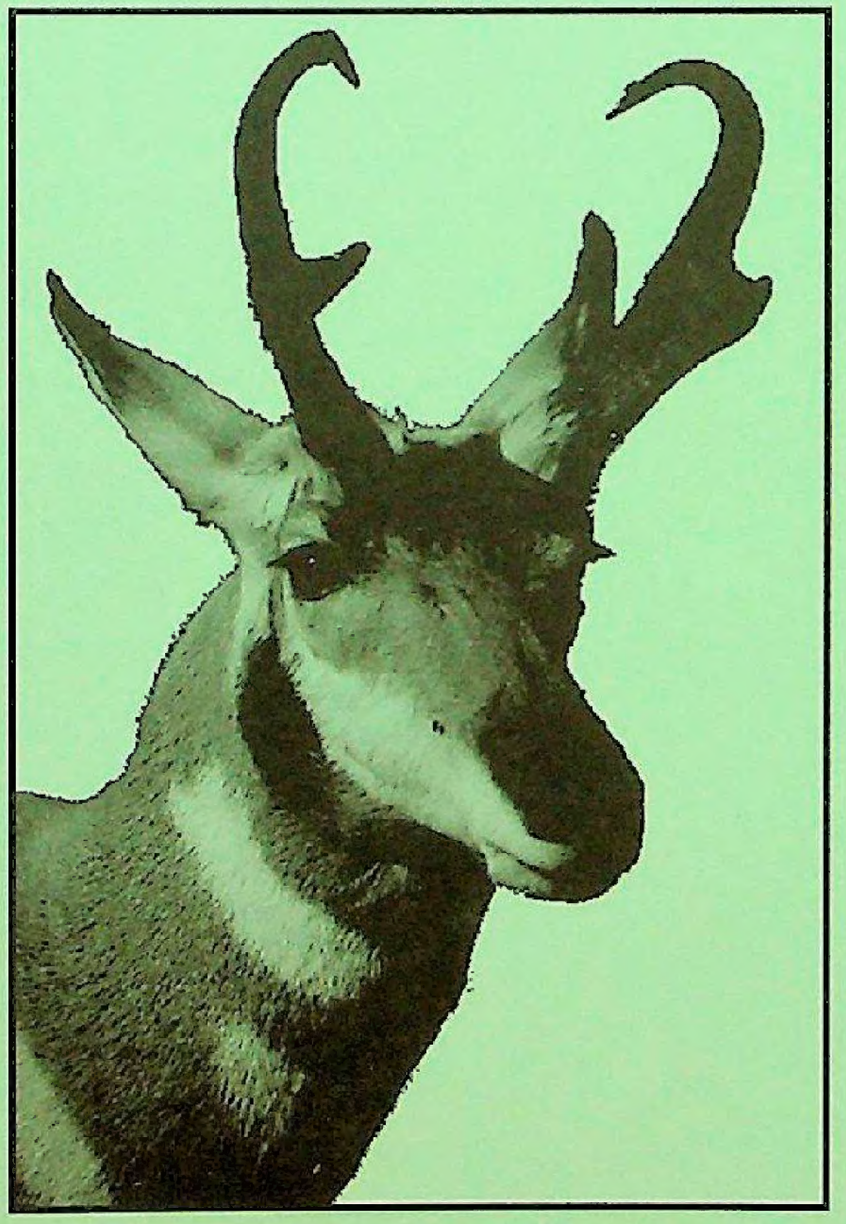
CALIFORNIA FISH and GAME

"CONSERVATION THROUGH EDUCATION"

VOLUME 84 WINTER 1998 NUMBER 1



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CONTENTS

ARTICLES

Extension of 2 Nonindigenous Fishes, *Acanthogobius flavimanus* and *Poecilia latipinna* into San Diego Bay Marsh Habitats ....Gregory D. Williams, Julie S. Desmond, and Joy B. Zedler 1

Nondestructive Diet Analysis of the Leopard Shark from 2 Sites in Tomales Bay, California .... Jason D. Webber and Joseph J. Cech, Jr. 18

Population Size of the Peninsular Pronghorn in Baja California Sur, Mexico ..... Jorge Cancino, Alfredo Ortega-Rubio, and Ricardo Rodriguez-Estrella 25

NOTES

Establishment of the Wakasagi, *Hypomesus nipponensis*, in the Sacramento-San Joaquin Estuary .... Geir A. Aasen, Dale A. Sweetnam, and Lisa M. Lynch 31

In-situ Videography Calibrated with 2 Parallel Lasers for Calculation of Fish Length ..... Marty L. Gingras, David A. VenTresca, and Richard H. McGonigal 36

An Economical, Portable Apparatus for Conducting Static Thermal and Chemical Toxicity Tests on Amphibian Eggs and Larvae ..... Mark R. Jennings 40

Use of Military Helicopters to Survey an Elk Population in North Coastal California..... ..... Floyd W. Weckerly and Karen E. Kovacs 44

Consumption of Juvenile Salmonids by Adult Steelhead in the Cowlitz River, Washington .... Geraldine E. Vander Haegen, Jack M. Tipping, and Stan A. Hammer 48

Editorial Guidelines 51

COVER

Male Pronghorn, *Antilocarpa americana*

California Fish and Game 84(1):1-17 1998

EXTENSION OF 2 NONINDIGENOUS FISHES, *ACANTHOGOBIUS FLAVIMANUS* AND *POECILIA LATIPINNA*, INTO SAN DIEGO BAY MARSH HABITATS

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Two nonindigenous fishes, the yellowfin goby, *Acanthogobius flavimanus*, and sailfin molly, *Poecilia latipinna*, were found in a variety of intertidal wetland habitats in Sweetwater Marsh National Wildlife Refuge in San Diego Bay, California. This is the first published documentation of these species in San Diego County tidal wetlands and an extension of their known ranges. The yellowfin goby, one of the larger species in the marsh fish assemblage and a generalist predator, was common in samples throughout the refuge (44% frequency of occurrence [FO] in large channels). Although mean densities were low (0.04 individuals/m^2), all size classes were present, suggesting a self-sustaining population. Adult sailfin mollies, which are largely herbivorous, were less common in channels (11% FO in locations sampled), but were concentrated in areas with modified tidal action and pooling surface water. Juvenile sailfin mollies (<15 mm total length) were collected on the marsh surface from shallow, hypersaline (>40‰) puddles from August to October 1995, despite extreme temperatures (>30°C). We recommend management actions that reduce off-season freshwater inflows and return tidal action to impounded saltmarsh areas in order to favor native species and prevent further spread of exotics.

INTRODUCTION

Introduction of harmful nonindigenous species is an international problem that has received increased attention by the scientific community and general public in recent years (U.S. Congress 1993, Carey et al. 1996, Kareiva 1996). Effects of exotic species on native ecosystems can be substantial: they modify basic ecosystem processes (e.g., primary productivity, hydrology, nutrient cycling, decomposition, disturbance regimes), alter habitat structure and food webs, introduce disease, and provide a novel source of predation and competition (Groves and Burdon 1986, Vitousek and Walker 1989, Nichols et al. 1990, D'Antonio and Vitousek 1992). The net result of these cumulative effects is often the endangerment or extinction of native species (U.S. Congress 1993).

The introduction of exotic fishes was a common practice in California over the past century (McGinnis 1984, Swift et al. 1993, Dill and Cordone 1997, Moyle 1997). Many of the >100 introductions to California's fresh and marine waters were intentional, mainly to create recreational fisheries; others were accidental, through

ballast water exchange or the release of aquarium pets (Baltz 1991, Carlton and Geller 1993, Swift et al. 1993). Successful establishment of exotic fishes is more likely in aquatic systems permanently altered by human activity (Moyle and Light 1996). California's waterways, which have been dammed, diverted, and channelized extensively over the past century, have provided ample opportunities for the establishment and spread of exotic fishes (Herbold and Moyle 1986, Moyle 1997).

The yellowfin goby, *Acanthogobius flavimanus*, is an estuarine fish native to Japan, Korea, and northern China. It is established in California and parts of Australia, where it is thought to have been introduced via ballast water of cargo ships (Middleton 1982). The first documented occurrence of the yellowfin goby in California was in the Sacramento-San Joaquin Estuary in 1963 (Brittan et al. 1963). Within 20 years, it became one of the most abundant species in the upper estuary (Brittan et al. 1970, Moyle et al. 1986, Wang[1] 1986). It subsequently became established in large, urbanized bays along the southern California coast, including Los Angeles Harbor (1977), Long Beach Harbor (1978), Newport Bay (1978), and in smaller lagoons near these localities (Miller and Lea 1972, Haaker 1979, Usui[2] 1981, Allen 1982, MEC Analytical Systems, Inc.[3] 1993). Its range has continued to expand southward to San Diego, and perhaps Baja California Norte, Mexico (C.A. Usui, personal communication, from Courtenay et al. 1986; Watson 1996). Yellowfin gobies were first collected off San Diego County in 1984 (San Dieguito River, Scripps Institute of Oceanography (SIO) fish collection 84-2; Mission Bay, SIO 85-197) and later in San Diego Bay in 1988 (San Diego Unified Port District[4] 1990). A more recent inventory of San Diego Bay by Allen[5] (1996) found yellowfin gobies most commonly in shallow, vegetated habitats; they represented less than 0.01% of the total fish catch.

The sailfin molly, *Poecilia latipinna*, is native to fresh and brackish coastal water drainages of the southern Atlantic Coast of the United States and the Gulf of Mexico (Courtenay and Meffe 1989). It is established worldwide, with populations in Central America, Singapore, Australia, New Zealand, and Hawaii; it is also locally

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[1] Wang, J.C.S. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters, California: A guide to early life histories. Interagency Ecological Study Program for the Sacramento-San Joaquin Estuary, Technical Report 9.

[2] Usui, C.A. 1981. Behavioral, metabolic, and seasonal size comparisons of an introduced gobiid fish, *Acanthogobius flavimanus*, and a native cottid, *Leptocottus armatus*, from upper Newport Bay, California. M.S. Thesis, California State University, Fullerton, California, USA.

[3] MEC Analytical Systems, Inc. 1993. San Dieguito Lagoon Restoration Project Biological Baseline Study, March 1992-1993. Draft Technical Memorandum, San Onofre Marine Mitigation Project. Prepared for Southern California Edison, Carlsbad, California, USA.

[4] San Diego Unified Port District. 1990. South San Diego Bay Enhancement Plan, Volume I: Resources atlas, marine ecological characterization, bay history, and physical environment. Prepared by Michael Brandon Associates, Inc., San Diego, California, USA.

[5] Allen, L.G. 1996. Fisheries inventory and utilization of San Diego Bay, San Diego, California: 2nd annual report, FY 1995-96. Prepared for U.S. Navy, Naval Facilities Engineering Command, Contract No. N68711-94-LT-4033.

established in Arizona, California, and Nevada (Courtenay and Meffe 1989). In California, the sailfin molly has been found in the Salton Sea since the 1950s, where it is the most abundant species in canals, ditches, and shallow margin areas of the lake (Shapovolov et al. 1981, Black[6] 1985, Dill and Cordone 1997). Coastal populations have been reported in a slough near Oxnard and in Ballona Marsh in Los Angeles (Swift et al. 1993). It is a popular aquarium fish and most occurrences in new habitats have been attributed to the release of unwanted pets (Meffe and Snelson 1989).

Here we report recent collections of the yellowfin goby and sailfin molly in the Sweetwater Marsh National Wildlife Refuge (NWR) and document their abundance, distribution, length frequencies, and associated physicochemical conditions. The Sweetwater Marsh NWR is a 128-ha complex of natural and constructed wetlands representing the largest intact area of remaining wetland acreage in San Diego Bay (Fig. 1). Nonetheless, its hydrology has been substantially modified over the last century (Haltiner et al. 1997). In particular, it has been intersected by several leveed roadways and railroads, partially filled with dredge spoils, and subjected to altered fluvial regimes due to anthropogenic development on its perimeter and throughout its watershed. As a result, tidal circulation patterns have been altered, some areas have subsided, and geomorphologic modifications have changed hydrologic regimes (Haltiner et al. 1997).

METHODS

Fishes were collected from 3 aquatic habitats in Sweetwater Marsh NWR: 1) large 3rd- and 4th-order channels (Horton 1945, Strahler 1964), 2) small 1st- and 2nd-order creeks, and 3) marsh surface. Large channels were sampled from 1989 to 1996 and provide quantitative information on relative abundance, distribution, and size of fishes over a broad area of Sweetwater Marsh NWR during an 8-year period. In 1995 and 1996, sampling was expanded to examine species trends in small intertidal creeks and the marsh surface. Sampling methods were appropriate to the depth and tidal regime of each habitat.

Large Channels

Third- and fourth-order channels average >10 m wide (Odum 1984) and make up 15–35% of the total channel length in Sweetwater Marsh NWR and other California marshes (Pestrong 1965, Coats[7] et al. 1995, Desmond[8] 1996). Large channels were

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[6] Black, G.F. 1985. The Salton Sea sport fishery. Inland Fisheries, Region 5 Informational Bulletin 0010-5-1985. California Department of Fish and Game, Long Beach, California, USA.

[7] Coats, R.N., P.B. Williams, C.K. Cuffe, J.B. Zedler, D. Reed, S.M. Watry, and J.S. Noller. 1995. Design guidelines for tidal channels in coastal wetlands. Report prepared for the U.S. Army Corps of Engineers, Waterways Experiment Station, Vicksburg, Mississippi, USA.

[8] Desmond, J.S. 1996. Species composition and size structure of fish assemblages in relation to tidal creek size in southern California coastal wetlands. M.S. Thesis, San Diego State University, San Diego, California, USA.

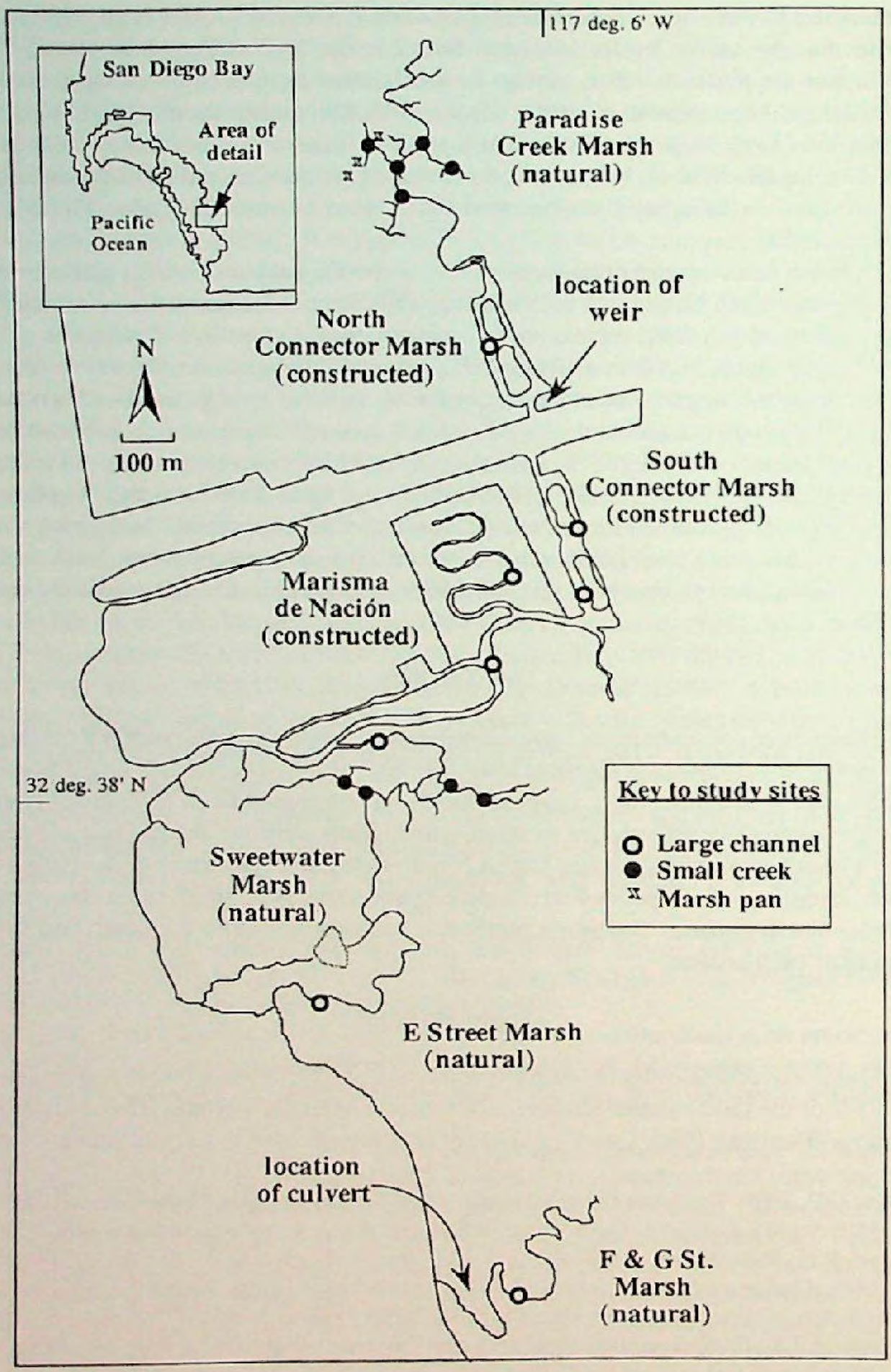

Figure 1. Sweetwater Marsh National Wildlife Refuge fish sampling locations.

characterized by a range of shapes, depths, elevations, and disturbance histories (some were recently constructed); however, all retained water at low tide. Channels were sampled during the low, slack portion of neap tides, using 2 blocking nets and one 15-m bag seine composed of 3-mm mesh. At each site, the blocking nets were deployed approximately 10–12 m apart, perpendicular to the channel to confine all fishes within this area. The bag seine was swept between the 2 blocking nets and across the channel to the opposite bank (1 pass). Passes were repeated (minimum of 3) until the number of fishes captured per pass approached 0. Total length (TL), to the nearest millimeter, of at least 25 individuals per species was recorded.

Fishes were sampled quarterly (March, June, September, and December) from among 8 sites throughout Sweetwater Marsh NWR between 1989 and 1991 (Fig. 1). From 1992 to 1996, fishes were sampled during summer (June and July), when dominant species generally were most abundant. Sampling at 2 sites was temporarily discontinued from 1991 to 1994 and 3 samples collected in summer 1992 were deleted from the data set because of inconsistent methods. In all, 90 samples were collected from large channels. Basic channel physicochemical variables, including depth (m), width (m), dissolved oxygen (mg/liter), temperature (°C), and salinity (‰) were measured concurrently.

Small Creeks

First- and second-order creeks average approximately 1 m and 4 m wide (Odum 1984), respectively, and generally make up 65–85% of total channel length in Sweetwater Marsh and other California marshes (Coats et al.[7] 1995, Desmond[8] 1996). These creeks, which usually drain completely at low tide, were sampled with modified channel nets (Shenker and Dean 1978). Nets consisted of 2 wings attached to a conical bag, all constructed of 3-mm nylon mesh, with lead and float lines attached. Channel nets were secured across the mouth of a creek at high slack tide and retrieved at low tide when the creek had drained and fish had been forced into the net with the ebbing tide. All fishes were counted and identified to species and, if sample size was large, a subsample of 100 fishes was measured to the nearest millimeter TL.

Intertidal creeks were sampled quarterly from July 1995 to April 1996. At least 6 sites were sampled in 2 remnant natural marshes, Sweetwater Marsh and Paradise Creek (Fig. 1), during each quarterly sampling period. Some of the intertidal creeks did not drain completely at low tide and fishes were observed in standing pools of water remaining in the creek beds. Pools at both locations were swept with a small, 3-mm mesh beach seine to qualitatively characterize species and size classes. Physical conditions were monitored in intertidal creeks using data loggers, which recorded bottom salinity, temperature, and dissolved oxygen at 15-minute intervals between high slack and low tide, while channel nets were deployed.

Marsh Surface

To sample fishes in puddles remaining on the vegetated marsh surface at low tide after the rest of the marsh surface had drained, six, 25-cm x 25-cm x 5-cm (0.0625m^2)

glass baking pans were spaced at 20-m intervals at decreasing elevations (+0.68 to +0.28 m National Geodetic Vertical Datum) along a transect in Paradise Creek (Fig. 1), and buried flush with the marsh surface. At low tide, the pans retained water as a natural depression would. Pans were swept with a 1-mm mesh dipnet weekly at low tide and all fish were measured to the nearest millimeter TL and identified to species. Dissolved oxygen, temperature, and salinity of pan water were recorded.

RESULTS

Yellowfin Goby

Yellowfin gobies were collected from Sweetwater Marsh NWR channels in every sampling year. They occurred throughout the refuge at all large channel sites and in 44% of all seine samples (Table 1). The yellowfin goby was the 8th most abundant of 19 species collected from large channels at Sweetwater Marsh NWR (Table 2). It made up slightly less than 1% of the total catch at a mean density of

Table 1. Physical conditions associated with sites where exotic species were collected in the Sweetwater Marsh National Wildlife Refuge. Frequency of occurrence for channels and creeks was determined by the percent of samples in which the species was collected; for pans, by the percent of sample dates in which the species was present in the pan transect. Values for dissolved oxygen (DO), salinity, and temperature represent bottom conditions. n/a = not applicable or not available because data loggers were not deployed or malfunctioned.

	3rd and 4th Order Channels	2nd Order Creeks	1st Order Creeks	Pans
Yellowfin goby				
% frequency of occurrence	44%	45%	11%	0%
Habitat parameter:				
DO (min-max, mg/liter)	2.7-14.0	2.0-7.8	n/a	
Salinity (min-max, ‰)	16.0-40.0	29.0-40.0	n/a	
Temperature (min-max, °C)	15.5-31.6	23.0-28.0	n/a	
Depth (max, m)	1.5	1.3	0.5	
Width (mean, min-max, m)	7.7, 3.9-18.9	3, 2-6	1, 1-2	
Sailfin molly				
% frequency of occurrence	11%	42%	30%	30%
Habitat parameter:				
DO (min-max, mg/L)	3.0-13.4	n/a	3.0-6.0	1.5-8.0
Salinity (min-max, ‰)	16.0-45.0	n/a	29.0-37.0	23.0-46.0
Temperature (min-max, °C)	15.0-29.8	n/a	21.7-28.0	13.5-33.0
Depth (max, m)	1.5	1.3	0.5	0.05
Width (mean, min-max, m)	7.6, 4.2-10.0	3, 2-6	1, 1-2	n/a

Table 2. Fish species collected from Sweetwater Marsh National Wildlife Refuge, with relative percentage species composition noted by habitat.

Species	3rd-4th-order channels % total	3rd-4th-order channels Density/m²	2nd-order creeks % total	1st-order creeks % total	Marsh surface % total
Arrow goby, *Clevelandia ios*	35%	1.684	12%	20%	2%
Topsmelt, *Atherinops affinis*	23%	1.122	31%	2%	
California killifish, *Fundulus parvipinnis*	18%	0.644	3%	20%	20%
Longjaw mudsucker, *Gillichthys mirabilis*	14%	0.553	43%	56%	38%
Shadow goby, *Quietula y-cauda*	4%	0.183	1%	<1%	
Bay goby, *Lepidogobius lepidus*	2%	0.095			
Cheekspot goby, *Ilypnus gilberti*	1%	0.055	<1%	<1%	
Yellowfin goby, *Acanthogobius flavimanus*[a]	<1%	0.040	8%	<1%	
Bay pipefish, *Syngnathus leptorhynchus*	1%	0.039	<1%	<1%	
Staghorn sculpin, *Leptocottus armatus*	<1%	0.018	<1%	<1%	
Diamond turbot, *Hypsopsetta guttulata*	<1%	0.007			
Sailfin molly, *Poecilia latipinna*[a]	<1%	0.005	<1%	1%	40%
Northern anchovy, *Engraulis mordax*	<1%	0.003			
Striped mullet, *Mugil cephalus*	<1%	0.003	<1%		
California halibut, *Paralichthys californicus*	<1%	0.002	<1%		
Round stingray, *Urolophus halleri*	<1%	0.002			
Deepbody anchovy, *Anchoa compressa*	<1%	0.001	<1%		
Halfbeak, *Hyporhamphus rosae*	<1%	0.001	<1%		
Slough anchovy, *Anchoa delicatissima*	<1%	0.001			
Spotted sandbass, *Paralabrax maculatofasciatus*			<1%		
Total number		25,140	2,535	1,272	169

[a] Nonindigenous species

0.040 individuals/m². The highest yellowfin goby density (0.093 individuals/m²) was found in the North Connector Channel (a constructed habitat), which is the site nearest Paradise Creek (Fig. 1). This is also one of the locations where sailfin mollies were abundant (see below).

When fish populations were sampled seasonally (1989–1991), yellowfin goby density peaked during summer (Fig. 2). Subsequent annual summer censuses yielded highly variable density estimates, ranging from 0.01 to 0.12 individuals/m². No obvious increases or decreases in yellowfin goby densities were discernible during the 8-year sampling period.

Yellowfin gobies made up 8% (203 individuals) of the total catch in channel net samples from 2nd-order creeks (Table 2). This high number was influenced strongly by a single Paradise Creek sample containing 181 individuals. Yellowfin gobies were rarely caught in 1st order creeks (<1%; 4 individuals) and were never collected in pans on the marsh surface.

Yellowfin gobies ranged in size from 25 to 239 mm and likely represent a viable breeding population (Fig. 3). Seasonal size trends were apparent, from recruitment

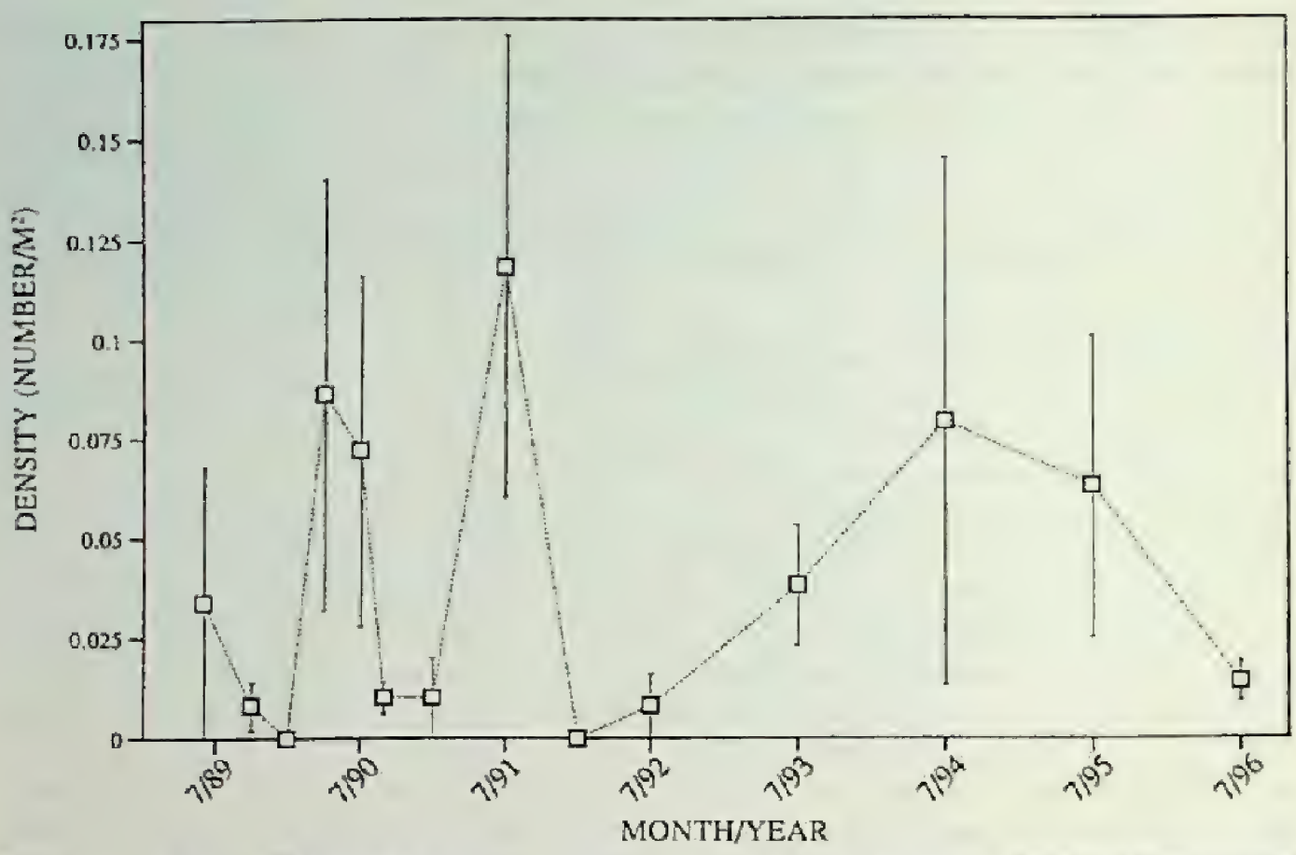

Figure 2. Yellowfin goby seasonal (1989 to 1991) and interannual (summers, 1992 to 1996) density estimates in 3rd- and 4th-order channels of Sweetwater Marsh. Vertical bars represent ±1 SE.

of small juveniles (20–60 mm) in spring to a summer size range of 20–140 mm and a fall size range of 80–160 mm. Several larger individuals (120–240 mm) were collected in marsh channels during winter.

Yellowfin gobies were collected from habitats with a wide range of physicochemical conditions: salinity, 16–40‰; temperature, 15.5–31.6°C; and dissolved oxygen, 2.7–14 mg/liter.

Sailfin Molly

Sailfin mollies were collected in channel samples as early as 1989. They appeared at 4 of the 8 large channel sites, but were most abundant and most frequently collected at North Connector Marsh, the site nearest Paradise Creek, and at F & G Street Marsh, at the south end of the refuge (Fig. 1). These sites have impeded drainage at low tide due to a weir and a culvert, respectively. Also, the marsh surface of Paradise Creek has been altered by numerous excavations where large numbers of reproducing sailfin mollies aggregate (G. Williams, personal observation).

Sailfin mollies were collected less frequently than yellowfin gobies in the large channels (11% frequency of occurrence), but were more common in 1st-order creeks, where they occurred in 30% of the samples (Table 1). Although sailfin mollies made up only 1% of the catch in 1st-order streams (Table 2), they may have been undersampled by the channel nets because they tended to stay in shallow pools in small creeks at low tide (J. Desmond, personal observation). When these pools were sampled with a small seine in Paradise Creek (n = 3), sailfin mollies were consistently

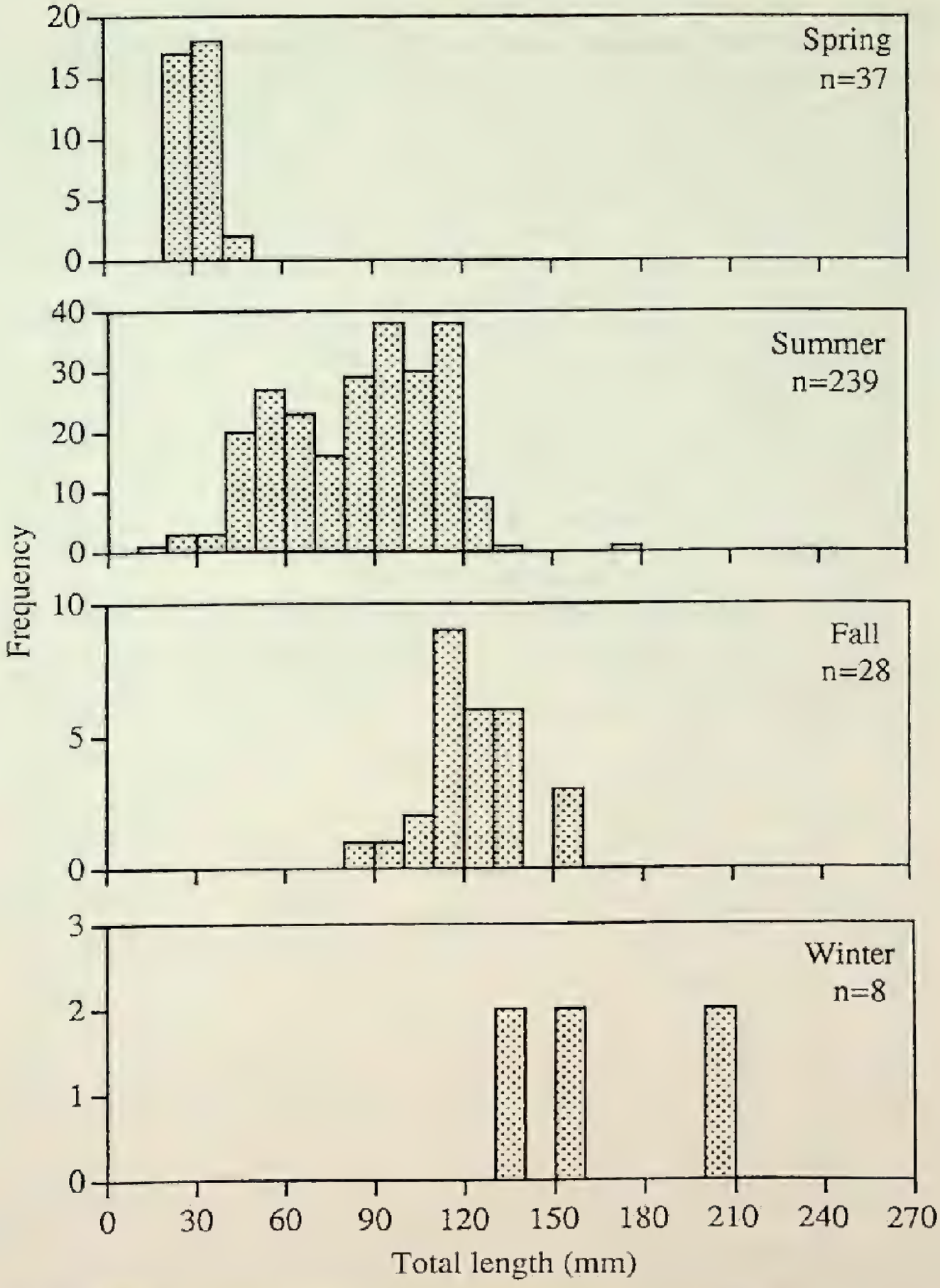

Figure 3. Yellowfin goby length frequency histograms by season, 1989–1996.

present.

The sailfin molly averaged fewer than 0.01 individuals/m^2 in large channels and was the 12th most abundant species in this habitat (Table 2). Overall abundance was relatively low, but data from seasonal sampling from 1989 to 1991 indicated a fall peak (Fig. 4). Because 1993–1996 sampling was conducted only in summer (when native species abundance peaked), the relative abundance of the sailfin molly may have been underestimated during the final 3 years of sampling. The population may have increased over time, based on summer samples; sailfin mollies were rarely collected in summer samples between 1989 and 1992, but they were frequently collected in summer from 1993 to 1996 (Fig. 4).

The sailfin molly was the most abundant, and the only exotic, species collected from the marsh pans, making up 40% of the catch (Table 2). Three native species were also collected (in order of decreasing abundance): longjaw mudsucker, *Gillichthys mirabilis*; California killifish, *Fundulus parvipinnis*; and arrow goby, *Clevelandia ios*. Juvenile sailfin mollies (6–13 mm) were collected between August and October, when temperature for successful reproduction (23.8°C; Dill and Cordone 1997) was likely achieved. Their presence overlapped with that of California killifish, which were present between May and October, but not longjaw mudsucker, which were only collected between March and July.

Differences in size structure between habitats indicated shifts in habitat use with age. While marsh pan collections were dominated by small (6–13 mm) individuals that were rarely collected in other habitats, small intertidal creeks and large channels were inhabited by sailfin mollies ranging from 12 to 85 mm (Fig. 5). Furthermore,

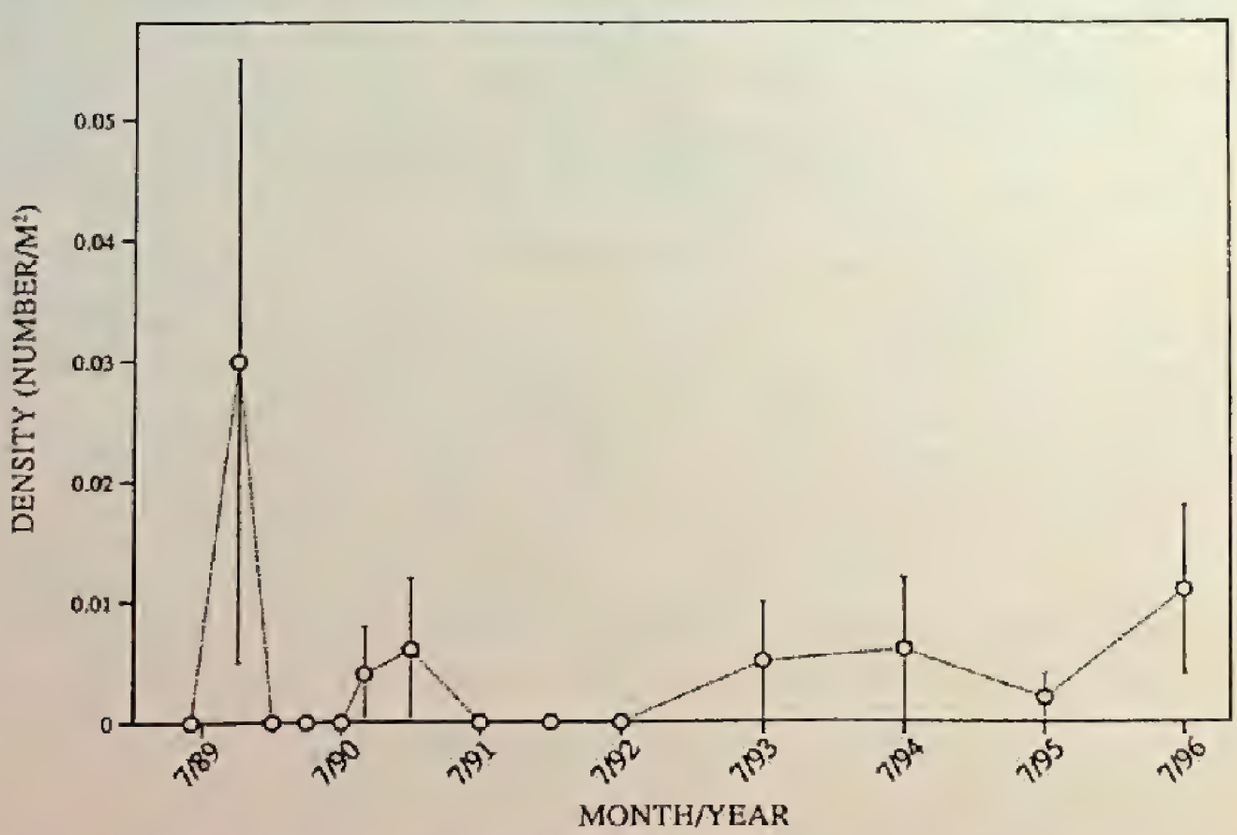

Figure 4. Sailfin molly seasonal (1989–1991) and interannual (summers, 1989 to 1996) density estimates in large 3rd- and 4th-order channels of Sweetwater Marsh. Vertical bars represent ±1SE.

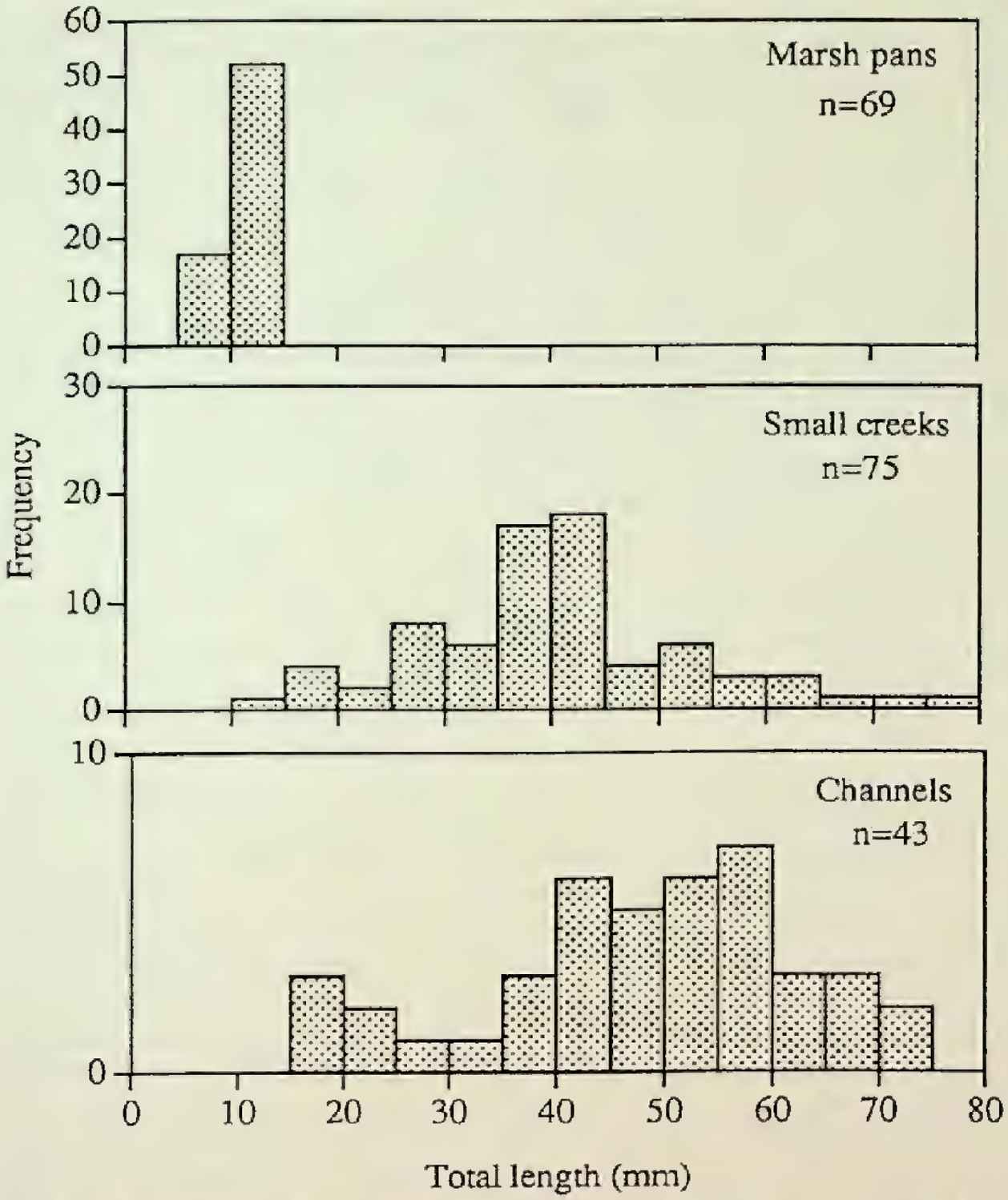

Figure 5. Sailfin molly length frequency histograms by habitat (marsh pans, small 1st- and 2nd-order creeks, large 3rd- and 4th-order channels), 1989–1996.

samples from small creeks were dominated by slightly smaller individuals (between 30 and 50 mm, mean = 40 mm) than those from large channels (dominant size class = 40–60 mm, mean = 48 mm) (Fig. 5).

Marsh pans were the most extreme environmental conditions in which sailfin mollies were collected. Here, mollies were found at salinities ranging from 23 to 46‰, temperatures ranging from 13.5 to 33.0°C, and dissolved oxygen levels as low as 1.5 mg/liter (Table 1).

DISCUSSION

Yellowfin goby

Several life history traits of the yellowfin goby predispose it to successful invasion of new habitats. These traits may negatively impact native fish assemblages. As a top carnivore that competes for food with native fish species (Brittan et al. 1970, Baker[9] 1979, Haaker 1979, Usui[2] 1981), the yellowfin goby may substantially modify the estuarine food web (Moyle and Light 1996). As one of the largest fish species in the marsh fish assemblage (to about 290 mm TL; Baker[9] 1979) and a piscivore, direct predation by yellowfin gobies could further alter the composition of the native fish assemblage. For example, yellowfin goby diets include juvenile topsmelt, *Atherinops affinis*, arrow gobies, (J. Desmond, unpublished data), and threespine sticklebacks, *Gasterosteus aculeatus*, (Baker[9] 1979). Because it is highly fecund (6,000–37,000 eggs/individual) and has a pelagic larval stage (Wang[1] 1986), it is likely to reproduce rapidly and disperse widely. Finally, because it is tolerant of a wide range of physicochemical conditions (Usui[2] 1981), the yellowfin goby is likely to become established in areas with widely varying, rapidly changing, or historically modified water quality.

Most (66%) of the yellowfin gobies collected in our samples were young-of-the-year <100 mm, suggesting that Sweetwater Marsh NWR channels were used as a nursery by juveniles. Yellowfin goby larvae move into upper bays and rivers in the spring using vertical migration to take advantage of tidal currents (Wang[1] 1986, Dotu and Mito 1955). Other studies have noted that juvenile yellowfin gobies (generally <85 mm TL) prefer tidal sloughs with muddy bottoms (Wang[1] 1986). Marsh channels likely function as good nursery habitat because they provide both a shallow water refuge from fish predators and an abundance of prey (Weinstein 1979, Boesch and Turner 1984).

Yellowfin gobies are tolerant of low salinities and have been collected frequently in rivers and freshwater canals (Brittan et al. 1970). Usui[2] (1981) demonstrated that yellowfin gobies experienced little metabolic stress at salinities of 15–25‰ and were less affected by these lower-than-seawater salinities than native staghorn sculpin, *Leptocottus armatus*. Yellowfin gobies, especially juveniles, are rare or absent in small coastal lagoons of southern California (Swift et al. 1993, Williams[10] 1996), where mouth closures are common, freshwater inputs are low, and resulting salinities are seasonally oceanic to hypersaline. Thus, constant freshwater inputs and ocean access, common to larger estuaries and native habitats in southeast Asia, may be

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[9] Baker, J.C. 1979. A contribution to the life history of the yellowfin goby (*Acanthogobius flavimanus*) in the San Francisco Bay-Delta area. M.S. Thesis, California State University, Sacramento, California, USA.

[10] Williams, G.D. 1996. The physical, chemical, and biological monitoring of Los Peñasquitos Lagoon: 20 September 1995–20 September 1996. Report to the Los Peñasquitos Lagoon Foundation, San Diego, California, USA.

necessary to sustain reproductive yellowfin goby populations. If this hypothesis is true, impending increases in freshwater inputs (run-off and treated wastewater) to smaller lagoons due to anthropogenic development (Trimble 1997) in the watersheds may enhance the yellowfin goby's ability to invade these habitats.

Sailfin Molly

The sailfin molly possesses a suite of characteristics that make it a successful invader and potential threat to native species, especially in disturbed habitats. In its native region, the sailfin molly is found in areas with poor water quality that few other fishes inhabit (Felley and Daniels 1992). Sailfin mollies are tolerant of extreme conditions and have been reported to withstand salinities ranging from 0 to 80‰ (Nordlie et al. 1992). Adults are largely herbivorous, opportunistic feeders (Harrington and Harrington 1961), so food resources are unlikely to be limiting. Furthermore, they are ovoviviparous and females can store sperm, making it likely that a single pregnant female can colonize a new area.

The sailfin molly and other closely related poeciliids exhibit aggressive behavior (Baird 1968, Meffe 1985). Schoenherr (1988) noted that male sailfin mollies interfered with reproduction of the endangered desert pupfish, *Cyprinodon macularius*, by courting both male and female pupfish. This behavioral interference is thought to be an important factor in the replacement of pupfish by sailfin mollies in the Salton Sea area (Schoenherr 1988). In aquaria, male sailfin mollies exhibited similar aggressive courtship behavior towards California killifish (G. Williams, personal observation). The co-occurrence of exotic sailfin mollies and native California killifish in the marsh pans suggests potential competition for spawning and nursery areas on the marsh surface.

Sailfin molly size-frequency data show a shift to deeper habitats with increasing size, a pattern observed in other marsh fishes, including the mummichog, *Fundulus heteroclitus*, on the Atlantic coast (Kneib 1984), and the California killifish in local estuaries (Desmond[8] 1996). Because almost all fishes (sailfin mollies, California killifish, longjaw mudsuckers, and arrow gobies) collected from the pans were small juveniles, the shallow marsh surface puddles that the pans were designed to simulate are presumed to act as nursery areas for these species. However, the function and relative importance of surface puddles to younger life classes remains to be investigated.

Conclusions and Recommendations

The presence of 2 exotic fishes in Sweetwater Marsh NWR shows that native fish assemblages have been altered, potentially stressing the aquatic ecosystem. Because the direct eradication of exotic species is costly and unlikely once exotic species become established (US Congress 1993), we recommend management actions that prevent further exotic species introductions and restore conditions that may reduce the abundance of these species in marsh habitats.

The influx of juveniles or larvae of exotic species should be halted by regulating

the discharge of ballast water into San Diego Bay. This could be done by limiting the volume of ballast water dumped, requiring its exchange at sea, or screening out organisms (Carlton and Geller 1993). The release of aquarium or bait fishes represents another introduction threat (Logan et al. 1986). These introductions may be curtailed by educating the general public of the threat exotic species represent, perhaps through posting notices at aquarium and bait stores.

Ecosystem management alternatives that reduce the level of disturbance to natural habitats and return historic hydrologic regimes that favor native species may reduce the abundance of yellowfin gobies and sailfin mollies in marsh habitats (Moyle and Light 1996, Moyle 1997). Saltmarsh channels that once drained completely have been converted into tidal impoundments by the construction of berms, dikes, and roads. These impoundments may be warmer than unrestricted channels and allow successful breeding of tolerant exotics, such as the sailfin molly. We recommend returning tidal action to impounded areas and increasing tidal drainage by removing weirs and enlarging culverts.

Efforts should be made to reduce off-season freshwater flows into San Diego Bay. Southern California's Mediterranean-type climate is characterized by high interannual variability in runoff, but a consistent seasonal pattern of pulsed flows of freshwater during winter and low flows during summer. Anthropogenic modifications have reduced winter flows through dam and reservoir construction and increased summer flows of imported water runoff via storm drains. As a result, freshwater-adapted species such as the yellowfin goby may thrive in competition with natives stressed by these conditions.

Monitoring should be continued in Sweetwater Marsh NWR to track native and exotic fish species population trends and to assess the success of management actions. Baseline monitoring and assessment are integral parts of any adaptive management strategy (Nyden and Zedler 1996). Finally, experimental studies are needed to examine competitive interactions between native and exotic species (e.g., Savino and Kolar 1996), with research that explores the role of disturbance in mediating exotic species success.

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LITERATURE CITED

Allen, L.G. 1982. Seasonal abundance, composition, and productivity of the littoral fish assemblage in upper Newport Bay, California. U.S. Fishery Bulletin 80:769-789.

Baird, R.C. 1968. Aggressive behavior and social organization in *Mollienesia latipinna* (Leseuer). Texas Journal of Science 20:157-176.

Baltz, D. 1991. Introduced fishes in marine systems and inland seas. Biological Conservation 56:151-177.

Boesch, D.F. and R.E. Turner. 1984. Dependence of fishery species on salt marshes: The role of food and refuge. Estuaries 7:460-468.

Brittan, M.R., A.B. Albrecht, and J.B. Hopkirk. 1963. An oriental goby collected in the San Joaquin River Delta near Stockton, California. California Fish and Game 49:302-304.

Brittan, M.R., J.D. Hopkirk, J.D. Conners, and M. Martin. 1970. Explosive spread of the oriental goby *Acanthogobius flavimanus* in the San Francisco Bay-Delta region of California. Proceeding of the California Academy of Sciences 38:207-214.

Carlton, J.T. and J.B. Geller. 1993. Ecological roulette: The global transport of nonindigenous marine organisms. Science 261:78-82.

Carey, J.R., P.B. Moyle, M. Rejmánek, and G. Vermeij. 1996. Preface to special issue on invasion biology. Biological Conservation 78:1-2.

Courtenay, W.R., D.A. Hensley, J.N. Taylor, and J.A. McCann. 1986. Distribution of exotic fishes in North America. Pages 675-698 *in:* C.H. Hocutt and E.O. Wiley, editors. The zoogeography of North American freshwater fishes. John Wiley & Sons, New York, New York, USA.

Courtenay, W.R. and G.K. Meffe. 1989. Small fishes in strange places: A review of introduced poeciliids. Pages 319-331 *in:* G.K. Meffe and F.F. Snelson, Jr., editors. Ecology and evolution of livebearing fishes (Poeciliidae). Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA.

D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. Annual Review of Ecology and Systematics 23:63-87.

Dill, W.A. and A.J. Cordone. 1997. History and status of introduced fishes in California, 1871-1996. California Department of Fish and Game, Fish Bulletin 176.

Dotu, Y. and S. Mito. 1955. On the breeding habits, larvae, and young of a goby, *Acanthogobius flavimanus* (Temminck et Schlegel). Japanese Journal of Ichthyology 4:153-161.

Felley, J.D. and G.L. Daniels. 1992. Life history of the sailfin molly (*Poecilia latipinna*) in two degraded waterways of southwestern Louisiana. Southwestern Naturalist 37:16-21.

Groves, R.H. and J.J. Burdon. 1986. Ecology of biological invasions. Cambridge University Press, New York, New York, USA.

Haaker, P. 1979. Two Asiatic gobiid fishes, *Tridentiger trigonocephalus* and *Acanthogobius flavimanus*, in southern California. Bulletin of the Southern California Academy of Sciences 78:56-61.

Haltiner, J., J.B. Zedler, K.E. Boyer, G.D. Williams, and J. Callaway. 1997. Influence of physical processes on the design, functioning, and evolution of restored tidal wetlands in California (USA). Wetlands Ecology and Management 4:73-91.

Harrington, R.W., Jr. and E.S. Harrington. 1961. Food selection among fishes invading a high subtropical salt marsh: From onset of flooding through the progress of a mosquito brood. Ecology 42:646-666.

Herbold, B. and P.B. Moyle. 1986. Introduced species and vacant niches. American Naturalist 128:751-760.

Horton, R.E. 1945. Erosional development of creeks and their drainage basins. Bulletin of the Geological Society of America 56:275-370.

Kareiva, P. 1996. Developing a predictive ecology for non-indigenous species and ecological invasions. Ecology 77:1651-1652.

Kneib, R.T. 1984. Patterns in the utilization of an intertidal salt marsh by larvae and juveniles of *Fundulus heteroclitus* (Linnaeus) and *Fundulus luciae* (Baird). Journal of Experimental Marine Biology and Ecology 83:41-51.

Logan, D.J., E.L. Bibles, and D.F. Markle. 1996. Recent collections of exotic aquarium fishes in the freshwaters of Oregon and thermal tolerance of Oriental weatherfish and pirapatinga. California Fish and Game 82:66-80.

McGinnis, S.M. 1984. Freshwater fishes of California. University of California Press, Berkeley, California, USA.

Meffe, G.K. 1985. Predation and species replacement in American southwestern fishes: A case study. Southwestern Naturalist 30:173-187.

Meffe, G.K. and F.F. Snelson, Jr. 1989. Ecology and evolution of livebearing fishes (Poeciliidae). Prentice-Hall, Englewood Cliffs, New Jersey, USA.

Middleton, M.J. 1982. The Oriental goby, *Acanthogobius flavimanus*, (Temminck and Schlegel), an introduced fish in the coastal waters of New South Wales. Australian Journal of Fisheries Biology 21:513-523.

Miller, D.J. and R.N. Lea. 1972. Guide to the coastal marine fishes of California. California Department of Fish and Game, Fish Bulletin 157.

Moyle, P.B. 1997. Fish invasions in California: Do abiotic factors determine success? Ecology 77:1666-1670.

Moyle, P.B., R.A. Daniels, B. Herbold, and D. Baltz. 1986. Patterns in distribution and abundance of a noncoevolved assemblage of estuarine fishes in California. Fishery Bulletin 84:105-117.

Moyle, P.B. and T. Light. 1996. Biological invasions of fresh water: Empirical rules and assembly theory. Biological Conservation 78:149-161.

Nichols, F.H., J.K. Thompson, and L.E. Schemel. 1990. Remarkable invasion of San Francisco Bay (California, USA) by the Asian clam *Potamocorbula amurensis*. 2. Displacement of a former community. Marine Ecology Progress Series 66:95-101.

Nordlie, F.G., D.C. Haney, and S.J. Walsh. 1992. Comparisons of salinity tolerances and osmoregulatory capabilities in populations of sailfin molly (*Poecilia latipinna*) from brackish and fresh waters. Copeia 1992:741-746.

Nyden, B. and J.B. Zedler. 1996. Sweetwater Marsh National Wildlife Refuge: Implementing adaptive management. Pages 105-108 *in:* J.B. Zedler, principal author. Tidal wetland restoration: A scientific perspective and southern California focus. Report No. T-038, California Sea Grant College System, University of California, La Jolla, California, USA.

Odum, W.E. 1984. Dual-gradient concept of detritus transport and processing in estuaries. Bulletin of Marine Science 35:510-521.

Pestrong, R. 1965. The development of drainage patterns on tidal marshes. Stanford University Publications, Stanford, California, USA.

Savino, J.F. and C.S. Kolar. 1996. Competition between nonindigenous ruffe and native yellow perch in laboratory studies. Transactions of the American Fisheries Society 125:562-571.

Schoenherr, A.A. 1988. A review of the life history and status of the desert pupfish, *Cyprinodon macularius*. Bulletin of the Southern California Academy of Sciences 87:104-134.

Shapavalov, L., A.J. Cordone, and W.A. Dill. 1981. A list of the freshwater and anadromous fishes of California. California Fish and Game 67:4-38.

Shenker, J.M. and J.M. Dean. 1978. The utilization of an intertidal salt marsh creek by larval and juvenile fishes: Abundance, diversity, and temporal variation. Estuaries 2:154-163.

Strahler, A.N. 1964. Quantitative geomorphology of drainage basins and channel networks. Pages 439-476 *in:* V.T. Chow, editor. Handbook of applied hydrology. McGraw-Hill, New York, New York, USA.

Swift, C.C., T.R. Haglund, M. Ruiz, and R.N. Fisher. 1993. The status and distribution of the freshwater fishes of southern California. Bulletin of the Southern California Academy of Sciences 92:101-167.

Trimble, S.W. 1997. Contribution of stream channel erosion to sediment yield from an urbanized watershed. Science 278:1442-1444.

U.S. Congress, Office of Technology Assessment. 1993. Harmful non-indigenous species in the United States. OTA-F-565, U.S. Government Printing Office, Washington, D.C., USA.

Vitousek, P.M. and L.R. Walker. 1989. Biological invasions by *Myrica faya* in Hawaii: Plant demography, nitrogen fixation, ecosystem effects. Ecological Monographs 59:247-265.

Watson, W. 1996. Gobiidae. Pages 1214-1245 *in:* H.G. Moser, editor. The early stages of fishes in the California Current region. California Cooperative Fisheries Investigations Atlas #33.

Weinstein, M.P. 1979. Shallow marsh habitats as primary nurseries for fishes and shellfish, Cape Fear River, North Carolina. Fishery Bulletin 77:339-357.

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NONDESTRUCTIVE DIET ANALYSIS OF THE LEOPARD SHARK FROM TWO SITES IN TOMALES BAY, CALIFORNIA

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Leopard sharks, *Triakis semifasciata*, were nondestructively sampled for stomach contents at 2 Tomales Bay sites during June and July 1996. Although prey items included 10 taxa at both locations, diets were found to be dominated by a single, different taxon at each location. *Cancer* crabs were found in 87% of the stomachs from the more exposed (Hog Island) location and *Urechis* worms were found in 82% of stomachs from the inner-bay (Indian Beach) location. Food habits differed by habitat in Tomales Bay and intertidal mudflat foraging was important at the inner-bay location.

INTRODUCTION

The leopard shark, *Triakis semifasciata*, is an abundant inshore shark found along the west coast of North America and is especially abundant in northern California bays (Love 1996). It is important to both sport and commercial fisheries (Russo 1975, Cailliet 1992, Love 1996). Past research has focused on understanding this species's biology and ecology (Ackerman 1971[1], Smith 1984, Smith and Abramson 1990, Cailliet 1992), including feeding habits (Russo 1975, Talent 1976). Leopard sharks are known to feed on fish, fish eggs, worms, clams, crabs, and other bottom dwelling invertebrates, but no information is available on site-specific feeding habits.

Our objectives were 1) to measure the site-specific dietary habits of leopard sharks at 2 Tomales Bay sites using a stomach eversion technique that did not require sacrificing the fish (Schurdak and Gruber 1989, San Filippo 1992) and 2) to compare our results with those from leopard shark dietary studies in other northern California bays and with those from the sympatric brown smoothhound, *Mustelus henlei*. Unlike data from previous studies that were collected from shark angling derbies, our study provides data on site-specific dietary habits.

METHODS

Sharks were collected from 2 sites in Tomales Bay (38°6'N, 122°54'W) between 28 June and 10 July 1996. The outer bay site was near the south end of Hog Island and the inner bay site was near Indian Beach (exact locations in Haeseker and Cech

[1] Ackerman, L.T. 1971. Contributions to the biology of the leopard shark, *Triakis semifasciata* (Girard) in Elkhorn Slough, Monterey Bay, California. M.A. Thesis, Sacramento State College, Sacramento, California, USA.

1993). Both sites were 3–6 m deep. The outer bay site was in an eel grass, *Zostera marina*, bed, whereas the inner bay site was on a mud flat. Both sites were sampled on 5 days. Most of the leopard sharks at the Indian Beach site were caught in the early part of the sampling period and at the Hog Island site, near the end of the sampling period. Gill-nets (100-m long x 3-m deep, with 6-cm mesh) were deployed from a 5.3-m outboard-powered skiff. Nets fished for 30–105 minutes, depending on the number of sharks that had to be processed. Upon capture, sharks were anesthetized for 10–15 minutes in a 60-liter cooler of seawater containing dissolved carbon dioxide supplied by a compressed CO_2 tank and diffuser stone (Summerfelt and Smith 1990).

Stomachs were everted using 25-cm-long forceps with the tips bent at about 45°. One person held the shark with the snout downward and the ventral surface facing away while the second person moved the stomach by massaging the ventral surface, lightly pushing cephalad with the fingers. The shark's mouth was held open and the forceps were gently inserted through the buccal cavity and into the stomach. The forceps were opened, turned slightly, and closed to hold a part of the pyloric region. By slowly pulling towards the mouth, the stomach folded in upon itself, causing the contents to spill out onto a mesh-covered bucket for collection. Often, larger individual food items had to be removed with the forceps before the stomach could be pulled outward. Afterwards, the shark was turned snout end up to allow the stomach to slide back into its natural position. If not initially successful, the technique was attempted several times or until the life of the fish was felt to be in danger. Although post-sampling survival was not measured, similar techniques performed on the closely related gray smoothhound, *Mustelus californicus*, and brown smoothhound showed minimal mortality (San Filippo 1992, Haeseker and Cech 1993). Length and sex were recorded and a small hole was punched in the dorsal fin to prevent future sampling of recaptured fish. The fish was revived with a flow of fresh seawater over its gills for 2–5 minutes and released.

Gut contents were temporarily stored in plastic zip-lock bags and preserved the same day in ethanol. Prey items were identified to at least genus using a dissecting microscope, dichotomous keys and diagrams (Brusca 1980, Smith and Carlton 1975, Morris et al. 1980), and reference specimens from the University of California Bodega Marine Laboratory museum. Undigested hard parts often allowed identification (e.g., crab legs and carapaces, *Porichthys notatus* jaws, and *Urechis caupo* posterior setae), and the relative size and number of hard parts allowed estimation of the number of prey. However, in some cases items were categorized as highly digested material. Because several hours elapsed between sample collection and preservation, the results may have been biased towards digestive-resistant forms.

Items were enumerated to calculate frequency of occurrence (F), percentage frequency (% F), and percentage by number (% N). Frequency of occurrence was the number of stomachs containing a prey item; % F was the value of F divided by the total number of stomachs containing at least 1 prey item, multiplied by 100. Percentage by number was the total number of a prey type divided by the total number of items found in all stomachs, multiplied by 100.

Volumetric displacement of each prey item was recorded to the nearest 0.5 ml and used to calculate the percentage by volume (% V), which is the total volume of a prey type divided by the volume of all prey, multiplied by 100. Volumetric displacement of partially digested items was estimated by measuring several whole specimens of that type and comparing the sizes of undigested hard parts to that of the reference group.

RESULTS

Thirty-three leopard sharks (23 females, 10 males) were collected for diet analysis. Total lengths ranged from 37 to 136 cm (mean = 93 cm) and mean size did not differ between sites (Hog Island = 91 cm; Indian Beach = 96 cm; $t = 0.67$, df = 31, $P > 0.05$). Mean number of prey items (overall mean = 2; Hog Island = 2; Indian Beach = 2; $t = 0.92$, df = 31, $P > 0.05$) and mean number of species (overall mean = 1; Hog Island = 1, Indian Beach = 2; $t = 0.18$, df = 31, $P > 0.05$) in stomachs also did not differ between sites. Seven sharks, 21% of the sample from each site, had empty stomachs. On two occasions sharks were seen regurgitating their stomach contents as they were being pulled from the water. Stress from entanglement in the nets may induce this behavior and probably accounts for part of the sample containing no food.

Two prey items, *Cancer* crabs, *Cancer* spp., and innkeeper worms, *Urechis caupo*, occurred in significantly different numbers in leopard sharks from the 2 sample sites (Table 1). *Cancer* crabs were an important constituent in the diet of sharks collected at Hog Island; they were found in 87% of the stomachs containing food, and represented 56% of the total items found. However, at Indian Beach, only 9% of the sharks contained *Cancer* crabs, and they made up only 3% of the total diet. Mean numbers of *Cancer* crabs in leopard shark stomachs were significantly different between sampling sites ($t = 3.72$, df = 31, $P < 0.05$). In contrast, innkeeper worms were seen in 82% of the stomachs from Indian Beach, accounting for 56% of the food items found. However, only 13% of the sharks from Hog Island had preyed on *Urechis*, which constituted only 6% of their diet. The mean number of innkeeper worms per shark at the Indian Beach site was significantly higher than that at the Hog Island site ($t = 2.65$, df = 31, $P < 0.05$).

Other prey items were taken in smaller numbers that did not vary significantly between sampling sites. Grapsid crabs, *Hemigrapsus* spp., were found in 13% of sharks collected from Hog Island, but in none from Indian Beach. Neither kelp crabs, *Pugettia* spp., nor pea crabs (e.g., *Scleroplax)* occurred in the sampled sharks. Similarly, no worm species besides innkeeper worms were found in any of the stomachs. Bay shrimp, *Crangon* spp., were found in 18% of the sharks at Indian Beach and in 13% at Hog Island, while ghost shrimp, *Callianassa* spp., were seen in 2 sharks from Hog Island only. The only recognizable fish found in the diet was the plainfin midshipman, *Porichthys notatus*, which was seen in 27% of the Indian Beach sample group. Unidentifiable fish remains were found in 7% of the Hog Island group. Fish eggs were found in 1 shark collected from Indian Beach. Clam siphons were found in 13% of the sharks from Hog Island, but none were seen in the Indian Beach

Table 1. Comparative mean percentage of number (% N), percentage frequency (% F), and percentage volume (% V) of prey items found in leopard sharks, *Triakis semifasciata*,caught near Indian Beach and Hog Island in Tomales Bay, California. n/a = not applicable.

	Indian Beach (n = 14)			Hog Island (n = 19)		
Prey type	% N	% F	% V	% N	% F	% V
Plant material	6.3	18.2	0	9.4	20.0	0
Urechis[a]	56.3	81.8	59.0	6.3	13.3	8.5
Cancer[a]	3.1	9.1	19.3	56.3	86.7	84.1
Hemigrapsus	0	0	0	6.3	13.3	3.1
Crangon	9.4	18.2	0.7	6.3	13.3	0.2
Callianassa	0	0	0	6.3	13.3	1.0
Clam siphons	0	0	0	6.3	13.3	0.4
Octopus	6.3	18.2	8.5	0	0	0
Fish eggs	3.1	9.1	0	0	0	0
Porichthys	9.4	27.3	12.3	0	0	0
Unidentified fish	0	0	0	3.1	6.7	2.8
Highly digested material	6.3	18.2	0.3	0	0	0
Empty	n/a	21.4	n/a	n/a	21.1	n/a

[a] Mean number of prey items differed significantly ($P < 0.05$) between sampling sites.

sharks. Two sharks from Indian Beach had each eaten an octopus, *Octopus* sp. Finally, eelgrass was found in 18% of the sharks from Indian Beach and 20% of those from Hog Island. Eelgrass was always found in stomachs containing other food items, indicating that it was probably taken incidentally when swallowing prey associated with it.

DISCUSSION

Previous dietary studies on leopard sharks relied upon data from sharks caught in fishing derbies (Russo 1975, Talent 1976). Although this method allows large numbers of animals to be processed, the results often imply a uniformity in prey selection across the species's range because capture site is not recorded. This method also biases data because sharks lured by bait may show preferences for bait-related prey items, which may be outside of their normal diet. Schurdak and Gruber (1989) noticed that up to 80% of their sample of lemon sharks, *Negaprion brevirostris*, caught on hook and line had empty stomachs, another source of bias. The use of gill nets at specific locations can reduce these biases, allowing a truer representation of the feeding habits of sharks in specific areas (Haeseker and Cech 1993) if the sharks are feeding locally. The latter is an untested assumption in our study.

Despite the relatively similar range in food items eaten at the 2 sampling sites, our data show a dramatic difference in the most frequently observed prey item between sites. Metabolic demands and consequent energy requirements are likely to be similar for all sharks in Tomales Bay (Haeseker and Cech 1993), yet the primary diet items were preyed upon differently at sites only 6 km apart. This can be explained by the abundance of these prey types at the 2 locations. Prey habitat requirements and

environmental conditions, such as salinity and substrate composition, dictate the distribution of prey items and, consequently, their abundance in predators' diets. Smith et al. (1991) described the outer bay as essentially oceanic habitat with oceanic salinities, while the inner bay has lower salinity and wider salinity fluctuations throughout the year. The intolerance of the *Cancer* crab, *Cancer gracilis*, to brackish water (Morris et al. 1980) probably restricts its distribution to the outer bay, corresponding to its high proportion in leopard shark stomachs at Hog Island. The more uniform salinities throughout the bay during summer (S.V. Smith and J.T. Hollibaugh, University of Georgia, Athens, Georgia, USA, unpublished data) might diminish its distributional variation. In contrast, the inner bay's extensive intertidal mud flats (Smith et al. 1991) are ideal for the innkeeper worm (Smith and Carlton 1975), matching the high proportion of this prey found in shark stomachs at Indian Beach.

How leopard sharks obtain *Urechis* is still unknown. These animals live in burrows up to 45 cm beneath the substrate surface (Morris et al. 1980). They may be captured either by shoveling with the rostrum (Russo 1975), or the sharks may quickly expand their pharyngeal cavities and suck them out of the burrows (Talent 1976). The innkeeper worms seen in our study were almost entirely intact, similar to Talent's (1976) observations. Curiously, no kelp crabs or pea crabs were found in the leopard shark stomachs, despite previous accounts that they are prey (Talent 1976, Russo 1975) and the pea crab's known commensal relationship with the innkeeper worm (Brusca 1980).

Other studies of leopard shark food habits show a similar diversity of prey. Russo (1975) found that the most commonly eaten prey were innkeeper worms and jacksmelt, *Atherinops californiensis*, in Tomales Bay and a variety of shrimp (*Crangon* spp., *Upogebia*, and *Callianassa* spp.) and *Cancer* crabs in San Francisco Bay. Leopard sharks from Elkhorn Slough preferred *Cancer* crabs, grapsid crabs, and innkeeper worms (Talent 1976). These previous studies found a wider variety of teleostean fish prey and a higher frequency of fish eggs in leopard shark stomachs than we did. Russo (1975) noted that some leopard sharks' engorgement with fish eggs was so complete that they regurgitated when handled. The lower frequency of fish eggs in our study may have been due to seasonal availability (Pacific herring, *Clupea pallasi*, spawn during winter in Tomales Bay) or to incomplete eversion of the stomachs (see below), which would limit collection efficiency of smaller items such as fish eggs. Bivalve clams with shells were common in sharks >100 cm (Talent 1976), but they were not found by either Russo (1975) or us.

Russo (1975) observed distinct differences in the types of food taken by leopard sharks and brown smoothhounds, which should reduce interspecies competition and allow co-existence. The only noteworthy dietary overlap between these species was a brown smoothhound preference for slender crabs, *Cancer gracilis*, at Hog Island (F = 75%) (Haeseker and Cech 1993).

Russo (1975) suggested that leopard sharks do little or no intertidal feeding, based on the absence of *Hemigrapsus oregonensis* from the diet study carried out in Tomales and San Francisco bays. However, Talent (1976) found that

H. oregonensis was an important food item in leopard sharks in Elkhorn Slough and concluded that leopard sharks feed intertidally there. Our data agree that *H. oregonensis* is not an important dietary component of leopard sharks in Tomales Bay. However, the obvious importance of the innkeeper worm in the diet at Indian Beach suggests that leopard sharks were feeding on Tomales Bay's intertidal mud flats where innkeeper worms build their burrows, often becoming exposed during low tides (Morris et al. 1980). During July 1996, leopard sharks were observed swimming in large congregations over mudflats located on the southern end of Tomales Bay in <1 m of water at high tide (J. Ackerman, M. Kondratieff, and S. Matern, University of California, Davis, California, USA, personal communication). Thus, we believe that leopard sharks feed intertidally in Tomales Bay and that intertidal organisms such as the innkeeper worm constitute an important part of their diet in the inner bay.

Some problems occurred with the stomach eversion technique. For example, even after practice on a dead specimen in the laboratory, it was not always possible to achieve complete stomach eversion in the field. This was especially true for larger sharks, a problem that might have been solved by using longer forceps. In most cases where complete eversion was not achieved, the stomach could be seen folded into the buccal cavity after the prey items had been removed from the shark. Recent calculations of the leopard shark's relatively low reproductive rate (Au and Smith 1997) encourages use of non-destructive sampling methods.

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LITERATURE CITED

Au, D.W. and S.E. Smith. 1997. A demographic method with population density compensation for estimating productivity and yield per recruit of the leopard shark (*Triakis semifasciata*). Canadian Journal of Fisheries and Aquatic Sciences 54:415-420.

Brusca, R.C. 1980. Common intertidal invertebrates of the Gulf of California. Second edition. The University of Arizona Press, Tucson, Arizona, USA.

Cailliet, G.M. 1992. Demography of the central California population of the leopard shark (*Triakis semifasciata*). Australian Journal of Marine and Freshwater Research 43:183-193.

Cortes, E. and S. Gruber. 1990. Diet, feeding habits, and estimates of daily ration of young lemon sharks, *Negaprion brevirostris* (Poey). Copeia 1990:204-218.

Haeseker S.L. and J.J. Cech, Jr. 1993. Food habits of the brown smoothhound shark (*Mustelus henlei*) from two sites in Tomales Bay. California Fish and Game 79:89-95.

Hyslop, E.J. 1980. Stomach content analysis – a review of methods and their application. Journal of Fish Biology 17:411-429.

Love, M. 1996. Probably more than you want to know about the fishes of the Pacific Coast. Second edition. Really Big Press, Santa Barbara, California, USA.

Morris R.H., D.P. Abbott, and E.C. Haderlie. 1980. Intertidal invertebrates of California. Stanford University Press, Stanford, California, USA.

Russo, R.A. 1975. Observations on the food habits of leopard sharks (*Triakis semifasciata*) and brown smoothhounds (*Mustelus henlei*). California Fish and Game 61:95-103.

San Filippo, R. 1992. Diet and gastric evacuation of gray smoothhound sharks, *Mustelus californicus*, from Elkhorn Slough National Research Reserve, Monterey Bay, California (Abstract). Page 161 *in:* Proceedings of the Eighth Annual Meeting of the American Elasmobranch Society.

Schurdak, M.E. and S.H. Gruber. 1989. Gastric evacuation of the lemon shark *Negaprion brevirostris* (Poey) under controlled conditions. Experimental Biology 48:77-82.

Smith, R.I. and J.T. Carlton. 1975. Light's manual. Third edition. University of California Press, Berkeley, California, USA.

Smith, S.E. 1984. Timing of vertebral band deposition in tetracycline-injected leopard sharks. Transactions of the American Fisheries Society 113:308-313.

Smith, S.E. and N.J. Abramson. 1990. Leopard shark *Triakis semifasciata* distribution, mortality rate, yield, and stock replenishment estimates based on a tagging study in San Francisco Bay. Fishery Bulletin 88:371-381.

Smith, S.V., J.T. Hollibaugh, S.J. Dollar, and S. Vink. 1991. Tomales Bay metabolism: C-N-P stoichiometry and ecosystem heterotrophy at the land-sea interface. Estuarine and Coastal Shelf Science 33:223-257.

Summerfelt, R.C. and L.S. Smith. 1990. Anesthesia, surgery, and related techniques. Pages 213-272 *in:* C.B. Schreck and P.B. Moyle, editors. Methods for fish biology. American Fisheries Society, Bethesda, Maryland, USA.

Talent, L.G. 1976. Food habits of the leopard shark, *Triakis semifasciata*, in Elkhorn Slough, Monterey Bay, California. California Fish and Game 62:286-298.

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POPULATION SIZE OF THE PENINSULAR PRONGHORN IN BAJA CALIFORNIA SUR, MEXICO

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Peninsular pronghorn, *Antilocarpa americana peninsularis*, population survey results from 1979 to 1991 were compared with the results of an April 1993 survey which counted 135 peninsular pronghorns, the highest ever recorded. We identify the probable main factors affecting the subspecies and propose recommendations for additional studies and suggestions for management of the population and its habitat.

INTRODUCTION

The peninsular pronghorn, *Antilocapra americana peninsularis*, is one of the most endangered large mammals in Mexico (Diario Oficial 1994, IUCN 1994). Its historical range encompassed about one-half of the Baja California peninsula (Hall 1981), but presently includes only a fraction of that (Fig. 1). To protect the peninsular pronghorn, it is essential to determine its population size and assess its status.

In this paper we present results of the April 1993 peninsular pronghorn population survey and compare them to those of previous population surveys. In addition, we discuss some factors potentially limiting the recovery of the population. We also suggest potential conservation measures and studies to answer specific habitat relationship questions.

METHODS

The study area is part of the Vizcaíno subdivision of the Sonoran Desert (Fig. 1) (Shreve and Wiggins 1964), consisting of plains with low, scattered vegetation (Brown and Webb 1979, Padilla et al. 1991). Ortega and Arriaga (1991) present a detailed description of this area. The climate is very dry and warm, with mean annual precipitation of 8.5 cm and mean annual temperature of 18–22°C. Most precipitation occurs during summer (Salinas-Zavala et al. 1991). The soil is mostly of the calcareous Regosol type (Maya and Troyo, 1991), with a sandy texture, little organic material, and high salinity. Vegetation is mainly sarcocaulescent and halophytous scrub (León de la Luz et al. 1991). Sarcocaulescent scrub is dominated by succulent shrubs, *Euphorbia xantii*, *Cercidium sonorae*, and *Jatropha cinerea*. Halophytous scrub is dominated by species with high tolerance to salt, *Euphorbia misera*, *Abronia gracilis*, and *Eriogonum intricatum*. The area is highly influenced by heavy coastal

fog that blankets the area, mainly in spring, and produces abundant epiphytic plants, e.g., *Tillandsia recurvata* and *Rocella tinctoria* (León de la Luz et al. 1991).

From 15 to 20 April 1993, we conducted ground and aerial population surveys of the peninsular pronghorn in the Vizcaíno Desert. The ground survey was performed with 3 teams, each with 1 vehicle and 2 observers. Each team surveyed a different area: the northern, central, and southern desert. To avoid exposure of the remaining peninsula pronghorns to poaching, specific areas surveyed are not shown in Fig. 1. Observers were equipped with 10x50 binoculars. Daily surveys began at 0600 and finished at 1900 hours. Vehicles traveled over the study area, mainly on old roads, at 60 km/hour average speed, with stops at vantage points. A total of 468 personnel-hours was spent in the terrestrial survey, which covered 1,600 km^2.

Concurrent with the ground survey, an aerial survey was conducted with a Cessna 182 airplane with 1 pilot and 2 observers. It flew at 90 km/hour on east-west transects at 1,000-m intervals at an average height of 100 m. There were 2 flights per day and flights averaged 150 minutes. Approximately 2,500 km^2 was searched on 207 aerial transects in 27 hours of flight.

The following information was recorded for each peninsular pronghorn observed: date, time of day, group size, sex, and age class (adult, juvenile, or fawn). Location and direction of travel were determined with a Global Positioning System instrument and noted on 1:100,000 maps (Crumpton 1991). Both ground and aerial records were plotted on 1:100,000 maps and compared to avoid duplicate counts.

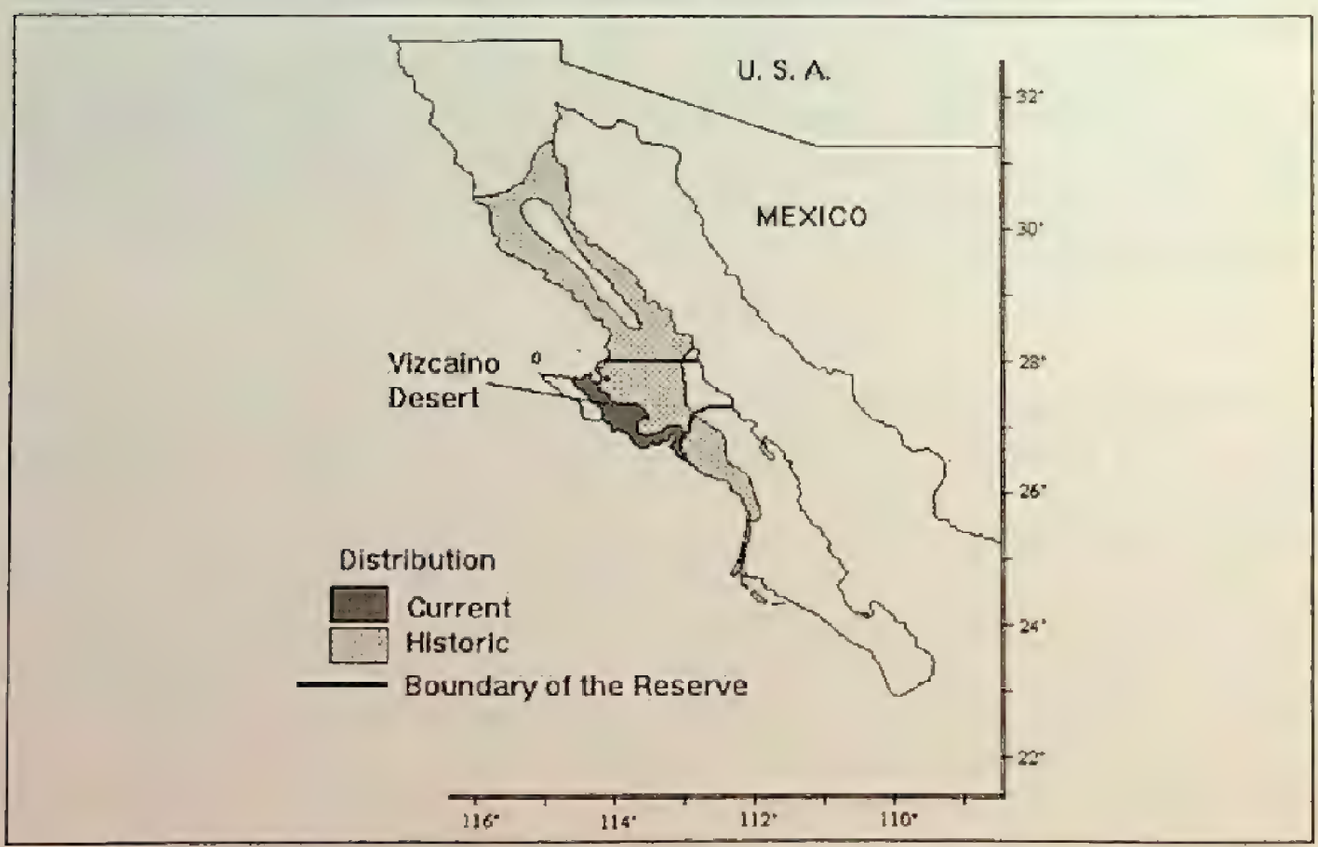

Figure 1. Location of the Vizcaíno Desert, Baja California Sur, Mexico, showing the current and historic range of peninsular pronghorn and the boundary of the Biosphere Reserve. (Modified from Cancino et al. 1994).

RESULTS

The numbers of peninsular pronghorns observed during the ground and aerial surveys in April 1993 were 51 and 121 individuals, respectively (Table 1). After ground and aerial counts were pooled, the population index of peninsular pronghorn was 135. These 135 individuals were observed in 17 different groups; 7 of these groups were observed in the central area. The sample consisted of 47 adult males, 53 adult females, and 35 fawns. The fawn:female ratio was 66:100 and male:female ratio was 89:100 (Table 1).

DISCUSSION

Fawn ratios differed from survey to survey. Such differences could be a result of the age of fawns. Peninsular pronghorn fawns are born in February and March (Sanabria et al. 1996), so surveys conducted during June and July only count older surviving fawns (Table 1). March and April surveys count new-born fawns that have not yet experienced much mortality.

Our ground survey data were similar to those obtained during previous ground surveys (Table 1). Areas searched and duration of search in most of the past surveys were approximately the same. There is no detailed information on the effort of previous surveys; however, the effort in the present survey is considered the minimum

Table 1. Results of surveys for peninsular pronghorn in the Vizcaíno Desert, Baja California Sur, Mexico. Data from 1979 to 1986 are from Jaramillo[1] (1989). Data from 1988 are from Gonzalez-Romero et al. (1991). A = aerial survey, G = ground survey, n/a = not available.

Year	Month	Survey type	Total counted	Ratio Male:female	Ratio Fawn:female	Sampling area (km²)
1977	Feb	G	83	96:100	43:100	n/a
1978	Jun	G	80	60:100	17:100[a]	n/a
1979	Oct	G	54	28:100	88:100[a]	n/a
1981	Jun	G	47	83:100	56:100[a]	n/a
1983	Dec	G	46	50:100	n/a	n/a
1984	Apr	A	53	62:100	81:100	n/a
1985	Mar	G	97	38:100	62:100	n/a
1988	Mar	G	48	65:100	75:100	n/a
1991	Mar	G	60	88:100	112:100	n/a
1993	Apr	G	51	94:100	37:100	1,600
1993	Apr	A	121	80:100	82:100	2,500
1993	Apr	A-G	135	89:100	66:100	2,500

[a]These ratios are for juvenile:female peninsular pronghorn born in February and March.

[1]Jaramillo, F. 1989. Contribución al conocimiento y conservación del berrendo de Baja California (*Antilocapra americana peninsularis*, Nelson 1912: Antilocapridae, Mammalia) en el Desierto de Vizcaíno, Baja California Sur, México. Bachelor Thesis, Universidad Nacional Autónoma de México, Mexico, D.F.

for an adequate census.

Our aerial survey results indicate that the population size in April 1993 was at least twice as large as our ground survey indicated. This indicates that our ground counts missed many animals. Also, our ground surveys were less effective than aerial surveys at detecting fawns. Jaramillo's[1] (1989) data from aerial surveys in 1981 and 1984 contradict our results because he found that fewer animals were observed in aerial searchs than in ground surveys. Many factors may explain the differences between ground and aerial surveys and among surveys conducted at different times. These include different observers, routes, effort, surveyed areas, topography, and vegetation type, as well as seasonal variation in pronghorn behavior.

Because of the limitations of our study, we cannot determine that every group observed constituted a separate herd. Hence, we do not know the herd ranges or the extent of genetic interchange among herds as the result of seasonal movements. Also, we do not know the extent of migration and its effect on gene flow. Special studies to obtain this information are necessary, including year-round efforts to determine composition, home range, and distribution of herds. Because of the endangered status of the peninsular pronghorn, the genetic diversity of the remaining population should be determined in the very near future.

The high proportion of males in the population suggests that trophy hunting is not a serious problem. However, non-sex-selective hunting for food by local people or opportunistic random shooting by travelers may be a continuing source of mortality. We have no data on hunting mortality, but access to the Vizcaíno Desert is available over many roads and is not controlled. In addition, 4-wheel-drive vehicles can reach off-road areas.

There are positive factors working for the conservation of the peninsular pronghorn. Three measures have been enacted to protect it: 1) hunting has been prohibited since 1922, 2) the Vizcaíno Desert flatland was included as part of a Biosphere Reserve in 1988 (Diario Oficial 1988), and 3) the peninsular pronghorn was added to the list of endangered species in 1994 (Diario Oficial 1994, IUCN 1994). Nevertheless, the threat of habitat degradation, mainly by agriculture, cattle grazing, and mining, remains.

It is possible that the population has increased slightly since the early 1990s. Despite this favorable change, more studies are required to obtain a more complete biological and ecological understanding of the peninsular pronghorn. Systematic population surveys and monitoring of mortality sources and rates, mortality differences by sex, genetic status, availability and quality of forage, and carrying capacity, should be conducted. Studies on interspecific relationships, such as predation (Sanabria et al., 1995, 1996) and competition are also needed.

Absent information from these suggested studies, immediate practical management initiatives are crucial. These include a widely promoted environmental education campaign and, most importantly, stricter protection measures. Immediate protection measures should include patrolling by the local authorities of the current range of distribution, especially the central part where most of the herds are concentrated. Check points should be established at the access to the only paved

road in the area to search for rifles and pronghorn remains. Habitat modification projects for cattle grazing and agriculture should be carefully assessed by the Federal authorities before granting approval.

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LITERATURE CITED

Brown, D.E. and P.M. Webb. 1979. A preliminary reconnaissance of the habitat of the peninsular pronghorn. Journal of the Arizona-Nevada Academy of Science 14:30-32.

Cancino, J., R. Rodríguez-Estrella, and A. Ortega. 1994. First aerial survey of historical range for peninsular pronghorn of Baja California, Mexico. Journal of Arizona-Nevada Academy of Science 28:46-50.

Crumpton, L.S. 1991. Baja explorer topographic atlas directory. Alti Publishing, San Diego, California, USA.

Diario Oficial. 1988. Decreto por el que se declara la Reserva de la biósfera "El Vizcaíno", ubicada en el Municipio de Mulegé, B.C.S. Diario Oficial de la Federación CDXXII (22): 2-27.

Diario Oficial. 1994. Norma Oficial Mexicana NOM-059- ECOL-1994, que determina las especies y subespecis de flora y fauna silvestres terrestres y acuáticas en peligro de extinción, amenazadas, raras y las sujetas a protección, y que establece especificaciones para su protección. Diario Oficial de la Federación CDLXXXVIII (10):7-35.

Garcia, E. 1964. Modificaciones al sistema de Clasificación Climática de Koeppen (paraadaptarlo a las condiciones de la República Mexicana). Instituto de Geografía, Universidad Nacional Aútonoma de México, México D.F.

Gonzalez-Romero A., J. Cancino, P. Galina, and S. Alvarez-Cardenas. 1991. El berrendo peninsular *Antilocapra americana peninsularis*. Pages 295-311 *in:* A. Ortega and L. Arriaga, editors. La Reserva de la Biosfera El Vizcaíno en la peninsula de Baja California. Centro de Investigaciones Biológicas de Baja California Sur, Publication No. 4. A.C. La Paz, Baja California Sur, México.

Hall, E.R. 1981. The mammals of North America. Volume II. Second Edition. John Wiley & Sons, New York, New York, USA.

IUCN (International Union for Conservation of Nature and Natural Resources). 1994. Red list of threatened animals. Cambridge, United Kingdom.

León de La Luz, J.L., J. Cancino, and L. Arriaga. 1991. Asociaciones Fisonomico-floristicas y flora. Capitulo 9, Pages 177- 212 *in:* A. Ortega and L Arriaga, editors. La Reserva de la Biosfera El Vizcaíno en la Península de Baja California. Centro de Investigaciones Biológicas de Baja California Sur, Publicación No. 4. A.C. La Paz, Baja California Sur, México.

Maya Y. and E. Troyo. 1991. Edafología. Capitulo 6, Pages 117-130 *in:* A. Ortega and L. Arriaga, editors. La Reserva de la Biosfera El Vizcaíno en la Península de Baja California. Centro de Investigaciones Biológicas de Baja California Sur, Publicación No. 4. A.C. La Paz, Baja California Sur, México.

Ortega, A. and L. Arriaga, editors. 1991. La Reserva de la Biosfera El Vizcaíno en la peninsula de Baja California. Centro de Investigaciones Biológicas de Baja California Sur, Publication No. 4. A. C. La Paz, Baja California Sur, México.

Padilla G., S. Pedrin, and E. Troyo-Dieguez. 1991. Geología. Capitulo 4. Pages 71-94 *in:* A. Ortega and L. Arriaga, editors. La Reserva de la Biosfera El Vizcaíno en la Península de Baja California. Centro de Investigaciones Biológicas de Baja California Sur, Publicación No. 4. A.C. La Paz, Baja California Sur, México.

Salinas-Zavala, C., R. Coria, and E. Díaz. 1991. Climatología y Meteorología. Capitulo 5. Pages 95-116 *in:* A. Ortega and L. Arriaga, editors. La Reserva de la Biosfera El Vizcaíno en la Península de Baja California. Centro de Investigaciones Biológicas de Baja California Sur, Publicación No. 4. A.C. La Paz, Baja California Sur, México.

Sanabria B., A. Ortega-Rubio, and C. Arguelles-Mendez. 1995. Food habits of the coyote in Baja California Sur, Mexico. Ohio Journal of Science 95:289-291.

Sanabria B., C. Arguelles-Mendez, and A. Ortega-Rubio. 1996. Occurrence of the endangered pronghorn *Antilocapra americana peninsularis* in coyote diets from Northwestern Mexico. Texas Journal of Science 48 :159-162.

Shreve, F. and I.L. Wiggins. 1964. Vegetation and flora of the Sonoran Desert. Stanford University Press, Stanford, California, USA.

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ESTABLISHMENT OF THE WAKASAGI, *HYPOMESUS NIPPONENSIS*, IN THE SACRAMENTO-SAN JOAQUIN ESTUARY

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Recent evidence indicates that the exotic wakasagi, *Hypomesus nipponensis*, is now resident in the Sacramento-San Joaquin Estuary, making it sympatric with the state and federally listed threatened delta smelt, *Hypomesus transpacificus*. Interactions between these similar species may affect delta smelt recovery.

The wakasagi is a member of the family Osmeridae. It was imported from Japan to California in 1959 by the California Department of Fish and Game (CDFG) as a forage fish for salmonids in lakes and reservoirs because it was believed to be the same species as the native delta smelt and capture of delta smelt was considered infeasible (McAllister 1963, Wales 1962). The delta smelt is an estuarine-dependent species found only in the Sacramento-San Joaquin Estuary and the lower parts of its tributaries (Moyle et al. 1992). Wakasagi were introduced into 6 reservoirs and lakes: Dodge Reservoir, Lassen County; Lake Shastina, Siskiyou County; Freshwater Lagoon, Humboldt County; Spaulding Lake, Nevada County; Jenkinson Lake, El Dorado County; and Big Bear Lake, San Bernadino County (Wales 1962) (Fig. 1). In 1972, wakasagi from Lake Shastina were introduced into Lake Almanor, Plumas County. Introductions occurred later in Lake Oroville, Butte County as wakasagi moved downstream through the North Fork Feather River from Lake Almanor (R. Decoto, CDFG, personal communication) and in Folsom Lake, Sacramento County through the South Fork American River from Jenkinson Lake (Hess et al.[1] 1995). Water released from Lake Oroville and Folsom Lake to the Sacramento-San Joaquin Estuary is the likely source of wakasagi introductions to the estuary. Water from the estuary is diverted into the California Aqueduct and the Delta-Mendota Canal for municipal and agricultural use by the State Water Project and Central Valley Project.

Because of the resemblance between wakasagi and delta smelt, wakasagi in the estuary were likely often mis-identified as delta smelt in the past. Thus, the scarcity of wakasagi records in the estuary since they were first collected there in 1974 (CDFG, unpublished data) may be due to mis-identification rather than rarity. Fin ray counts are of little value to separate the 2 species as their pectoral, anal, and dorsal counts overlap. However, wakasagi can be distinguished by the larger eyes

[1] Hess, L., C. Karp, and J. Wang. 1995. Sacramento perch, wakasagi, splittail, Sacramento blackfish, and shimofuri goby in San Luis Reservoir and O'Neill Forebay. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter, Autumn 1995:18-20.

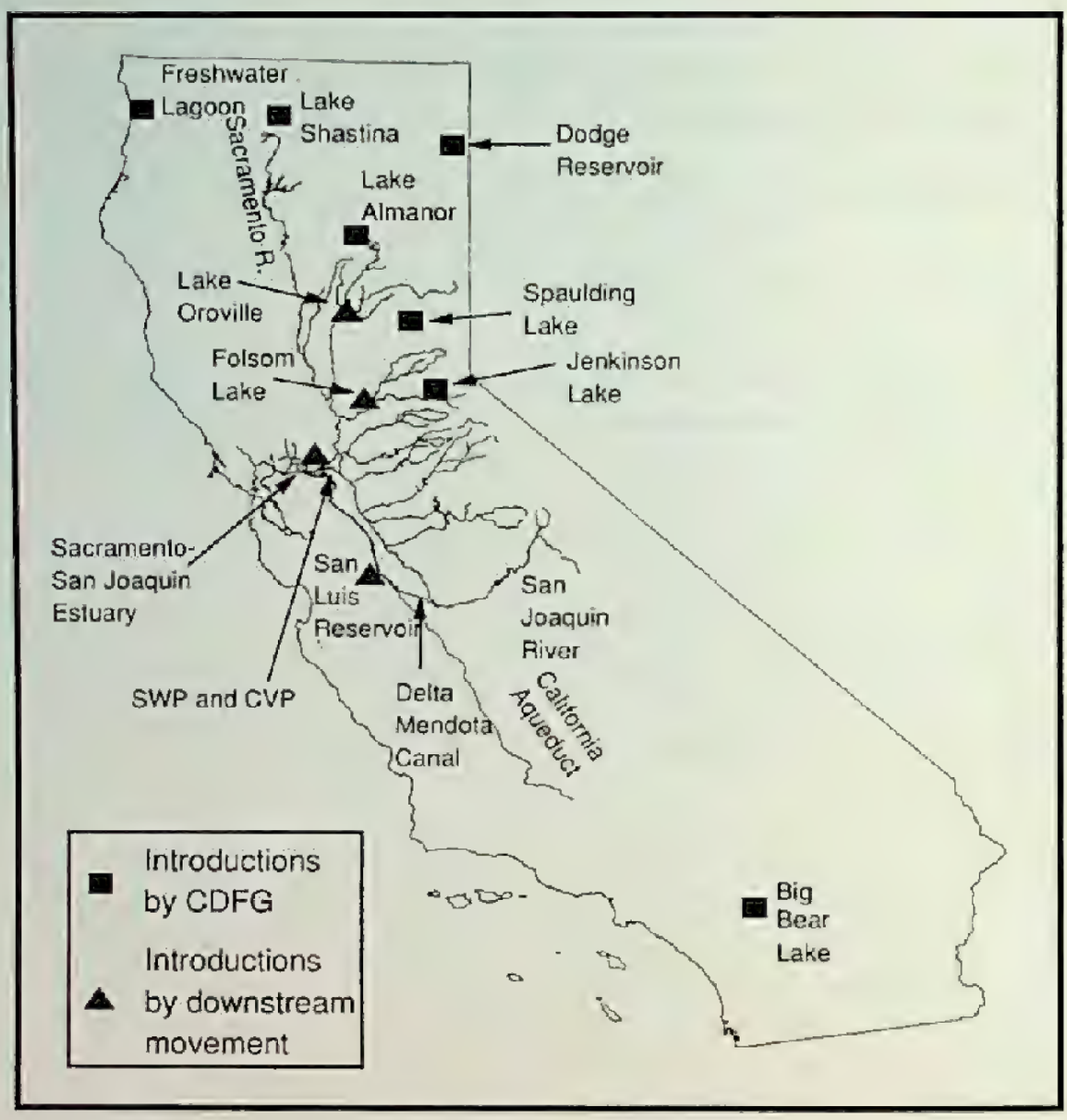

Figure 1. Introduction sites for wakasagi in California.

and the number of melanophores on the isthmus. A morphometric comparison of known wakasagi from Folsom Lake and Lake Almanor and delta smelt from the estuary showed that wakasagi have 5-77 melanophores on the isthmus, while delta smelt have ≤ 1 melanophore (Fig. 2). The numbers of melanophores in wakasagi from Folsom Lake and Lake Almanor were significantly and positively correlated with standard length ($r = 0.93$, $n = 42$, $P < 0.001$), meaning that the number of melanophores increases with size. Both species have numerous melanophores on the mandible.

Limited information exists on wakasagi life history and distribution in California. Wakasagi in Japan spawn in tributaries in the spring and the eggs are adhesive and attach to rocks and gravel (Wales 1962). The incubation period at 14.5°C is approximately 12 days and the larvae are carried downstream to lakes and reservoirs. Wakasagi reach sexual maturity when 1 year old and some live to spawn a 2nd year and can attain a fork length of 13 cm.

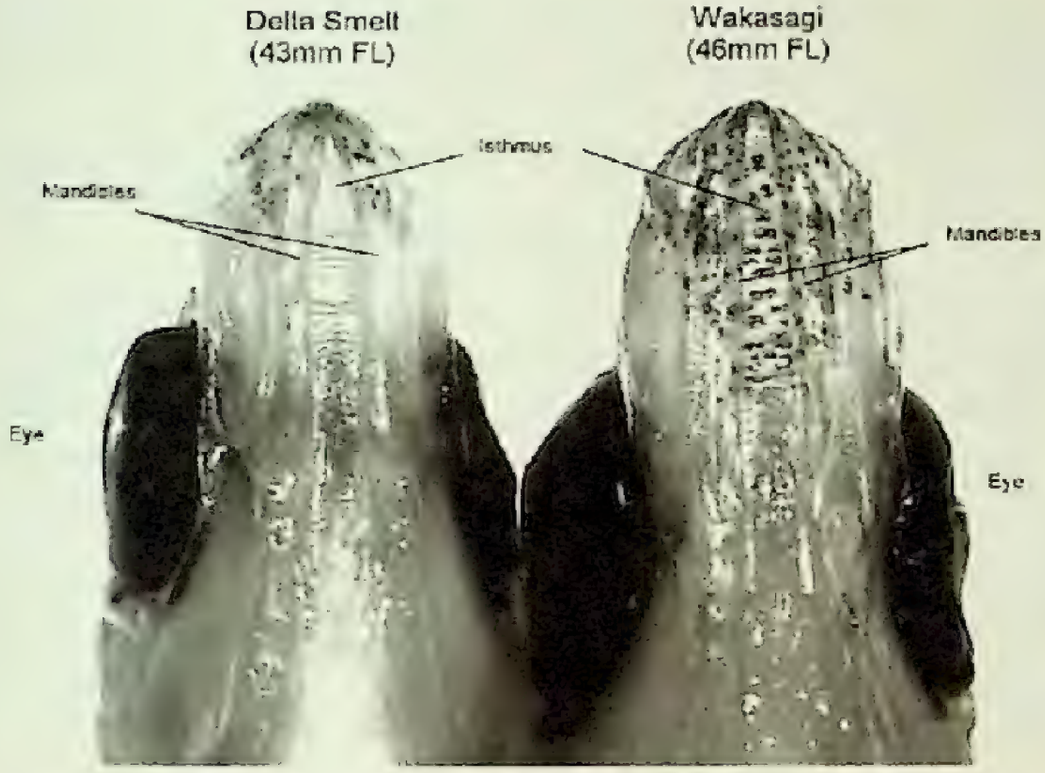

Figure 2. Comparison of melanophores in delta smelt and wakasagi. Wakasagi have 5-77 melanophores on the isthmus while delta smelt have ≤1 melanophore. Both species have numerous melanophores on the mandible. Note the larger eyes of wakasagi.

The wakasagi may have increased its range and abundance in the SacramentoSan Joaquin Estuary during the 1990s (CDFG, unpublished data). A resident population has been observed in the lower American River below Folsom Lake since at least 1991 and an apparent increase in the estuarine population occurred from 1994 to 1996, presumably due to high outflows flushing larvae and juveniles from upstream lakes and reservoirs (Wang[2] 1995).

Three CDFG surveys that target different life stages of smelt and sample the entire estuary (egg and larva survey, 20 mm survey, and midwater trawl survey) were used to determine the distribution and abundance of wakasagi in 1995 and 1996. The egg and larva survey samples smelt larvae from February to July (only Cache Slough was sampled in 1996), the 20 mm survey samples juveniles from April to August, and the midwater trawl survey samples adults from August to December.

All three surveys collected low numbers of wakasagi both years. Based on our sampling and a larva survey by the University of California, Davis (UCD) in the Suisun Marsh (S. Matern, UCD, personal communication), wakasagi postlarvae occurred in freshwater from Suisun Bay upstream to Cache Slough and the eastern Sacramento-San Joaquin Delta during winter and spring (Fig. 3). The absence of prolarvae in estuarine collections suggests that most wakasagi probably spawned above the estuary and some larvae may have been washed out of upstream reservoirs. Juveniles were collected from San Pablo Bay to the lower Sacramento and San Joaquin

[2] Wang, J. 1995. Observation of possible larval and prejuvenile and wakasagi/delta smelt hybrids in the delta and tributary streams. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter, Summer 1995:18-19.

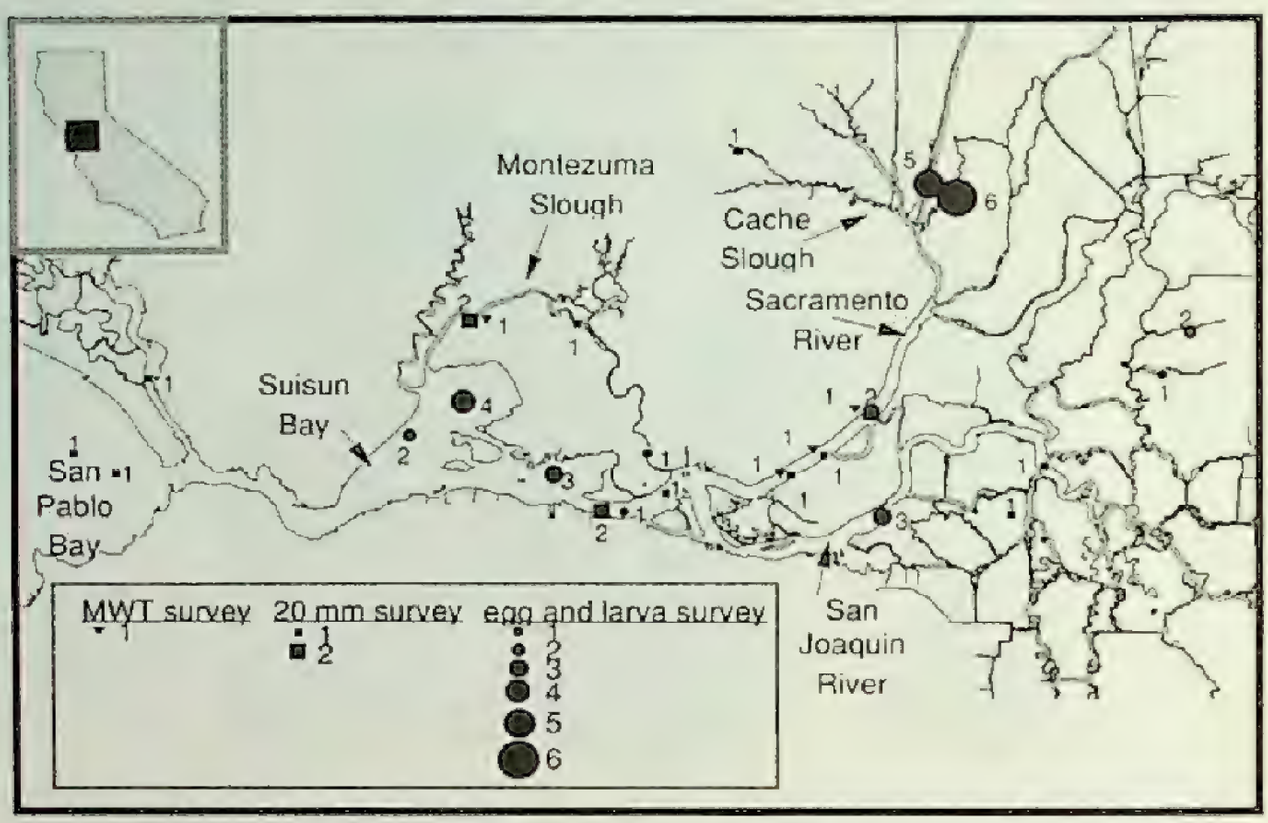

Figure 3. Wakasagi distribution and abundance (number of fish per station) in the Sacramento-San Joaquin Estuary during 1995-96. Larval wakasagi were sampled by the egg and larva survey, juveniles were sampled by the 20 mm survey, and adults were sampled by the midwater trawl survey (MWT).

rivers in 0-10 ‰ salinity, indicating that wakasagi are euryhaline. Adults were confined to the upper part of the estuary in the lower Sacramento River and Montezuma Slough in 1-3 ‰ salinity during late summer and fall. Wakasagi distribution in the estuary during 1995 and 1996 was similar to that of delta smelt (CDFG, unpublished data).

In 1994, wakasagi were found in San Luis Reservoir, Merced County, which is a storage facility for water exported from the Sacramento-San Joaquin Delta via the Delta-Mendota Canal and the California Aqueduct (Hess et al.[1] 1995). If not there already, it is likely that wakasagi also will be transported to several southern California reservoirs that receive water from the California Aqueduct. Based on documented distribution in the estuary, wakasagi also may occur in tributaries of San Pablo and San Francisco bays during years of high freshwater outflow.

The ecological effects of established wakasagi populations within the critical habitat of delta smelt are unclear. Since both species use similar habitats, they could compete for food and space. They have similar diets, feeding predominantly on calanoid copepods, including *Pseudodiaptomus forbesi* and *Eurytemora affinis* (CDFG, unpublished data). The presence of F1 hybrids in the estuary indicates that wakasagi can interbreed with delta smelt (Moyle[3] 1995). However, no backcross F2

[3] Moyle, P. 1995. Searching the origins of the delta smelt. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Newsletter, Spring 1995:9.

individuals have been observed and the high degree of genetic divergence between the 2 species suggests that F1 hybrids are infertile and that there is no genetic threat at the present time (Stanley et al. 1995). The sympatry of wakasagi and delta smelt may offer new opportunities for studying the biology of each species.

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LITERATURE CITED

McAllister, D.E. 1963. A revision of the smelt family, Osmeridae. National Museum of Canada Bulletin 191.

Moyle, P.B., B. Herbold, D.E. Stevens, and L.W. Miller. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 121:67-77.

Stanley, S.E., P.B. Moyle, and H.B. Shaffer. 1995. Allozyme analysis of delta smelt, *Hypomesus transpacificus* and longfin smelt, *Spirinchus thaleichthys* in the Sacramento-San Joaquin Estuary, California. Copeia 1995:390-396.

Wales, J.H. 1962. Introduction of pond smelt from Japan into California. California Fish and Game 48:141-142.

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IN-SITU VIDEOGRAPHY CALIBRATED WITH 2 PARALLEL LASERS FOR CALCULATION OF FISH LENGTH

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The availability of relatively inexpensive, powerful lasers makes laser-scaled photogrammetry feasible for a wide variety of assessments (e.g., density of benthic flora and fauna and fish length-frequency distributions). Various methods are used to analyze photographic data, from manual digitization of images from hardcopy printouts to completely automated processing based on pattern recognition. As an aid to those considering laser-scaled photogrammetry for assessment of fish length-frequency distributions, this paper describes the system we use, its potential biases and sources of error, and the analysis of data collected using the system.

We used in-situ videography with 2 parallel lasers for image scaling to assess the length-frequency distribution of several rockfishes, *Sebastes* spp., in kelp-bed habitat along the central California coast. Our system used two, 10-milliwatt red lasers in individual waterproof housings (superseded by Model MR-2 Waterproof; Laser Devices, Inc., Monterey, California[1]) mounted 50 mm apart, parallel to and equidistant from the optical axis of the video camera (TR-101 Hi-8; Sony USA[1]), on a hand-held underwater camera housing (SeaHawk; Light & Motion Industries, Inc., Monterey, California[1]). Fiducial marks from the lasers are projected onto fish during taping and images of the complete lateral aspect of fish and both marks are recorded.

The analysis process is completely computerized, but not automated. Individual frames are selected and digitized using a video frame grabber (Snappy; Play Inc., Rancho Cordova, California[1]). The images are calibrated and fish length is calculated using image analysis software (SigmaScan Pro; Jandel Inc., San Rafael, California[1]). Frame grabber and image analysis software are Windows applications and Technology-Without-An-Interesting-Name (TWAIN) compliant. The TWAIN compliance eliminates several image-file processing steps by allowing an image to be captured directly into image-analysis software workspace.

There are likely biases and sources of error in the calculation of fish length using this system. Most are introduced during data collection, while others are introduced during data analysis. Error in the alignment of the lasers is a source of bias. If the lasers diverge, then calculated fish length will be negatively biased with increasing range. If the lasers converge, then calculated fish length will be positively biased with increasing range. This bias is minimized by using sturdy laser mounts, by making regular calibrations of fiducial mark spacing, and by constraining the range within which fish are taped.

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[1] Reference to trade names does not imply endorsement by the California Department of Fish and Game.

Non-perpendicular long-axis orientation of the fish to the optical axis of the camera is a source of negative length bias. The spacing between fiducial marks projected onto a flat (rockfish-sized) surface varies slightly as the surface is rotated from a perpendicular orientation to the optical axis and, if the angle of orientation is known, then the distance between fiducial marks can be calculated. However, fish are not flat and during normal field work the angle of orientation cannot be measured. In practice, the videographer must attempt to record fish in a perpendicular orientation to the optical axis and the videotape analyst must recognize and process those images.

The relative distance between fiducial marks and fish length is a source of error (and possibly bias). This distance is used as a multiplication factor, and any error in the actual distance between fiducial marks will be propagated further when scaling the image of a longer fish. The error can be minimized by selecting the best images (with respect to previously described sources of bias and error) and by increasing the fiducial mark spacing:fish length ratio.

Field curvature due to camera optics is also a source of error. This effect causes geometrical distortion of an image. Our camera manifests negative distortion, which means that "...off-axis points are imaged at distances...shorter than nominal." (Jahne 1997:138). The error can be minimized by composing images so that the fish is centered on the optical axis and by reducing field size.

Calibration of fiducial marks in the image analysis software is another source of error. The calibration is made by relating the known distance between fiducial marks and the distance between the fiducial marks in the image on the screen (2-point rescaling). The distance between fiducial marks on the screen is calculated by placing a cursor on each point. When analyzing images where magnification during data collection is minimal or range to the fish is relatively great, each fiducial mark appears very small (e.g., 1 mm diameter) but is actually much larger (e.g., 5 mm diameter). It is difficult to position the cursor near the center of each fiducial mark, and thus easy to incorrectly calibrate the image. The error can be minimized by substantially magnifying the image (i.e., the fiducial marks) before 2-point rescaling.

With this system, fish length is more rigorously estimated by calculating lengths from several good images, rather than from a single good image. Images should not be of successive frames, but randomly sampled from several seconds of video. Doing so allows the incorporation of within-fish variance due to the interaction of all sources of error and bias. With this type of data, between-factor comparisons of mean lengths can be analyzed with repeated-measures ANOVA (ZAR 1984). The number of images that should be used varies with the statistical power desired and fish-specific characteristics (e.g., fish color and behavior).

We computed the precision of calculated fork lengths by analyzing 10 images from each of 20 kelp rockfish, *Sebastes atrovirens*, and from each of 20 gopher rockfish, *S. carnatus*. To minimize the effect of laser alignment, images were selected when the estimated range to fish was nearly constant for several seconds. For kelp rockfish, coefficient of variation averaged 2.3% and ranged from 1.1-5.2%. For

gopher rockfish, coefficient of variation averaged 5.8% and ranged from 1.9-10.9%. The precision of kelp rockfish calculated lengths was good, while those for gopher rockfish might be considered marginal. Several factors account for the difference in precision. For instance, gopher rockfish are closely associated with the substrate and complete lateral presentations and perpendicular long-axis orientations are difficult to record. Kelp rockfish are generally videotaped in mid-water, which makes it easier to record properly composed images. Also, gopher rockfish have many light-colored blotches or spots that reflect light with strong intensity, which makes defining the center of each fiducial mark relatively difficult. Kelp rockfish are uniformly light-colored; although light is strongly reflected, the center of each fiducial mark is easily defined.

We estimated the accuracy of calculated fork lengths by analyzing 3 images from each of 10 blue rockfish, *Sebastes mystinus*. The fish were videotaped, collected, and measured in a laboratory. For each fish, we determined the ratio of the mean calculated fork length to the corresponding measured fork length. The ratios averaged 105% and ranged from 98-116%. Accuracy of these calculated lengths was good, but lengths were positively biased. The bias is likely due to some combination of their length relative to the distance between fiducial marks (approximately 6:1), the relatively long range at which they were videotaped, and post-mortality factors (e.g., shrinkage).

As our system is configured and operated, length calculations of fishes that are some combination of mid-water oriented, predominantly dark, not blotched or spotted, and approachable (e.g., black rockfish, *Sebastes melanops*, and olive rockfish, *S. serranoides*) should be relatively precise and accurate. Large fishes that are either active swimmers (e.g., California sheephead, *Semicossyphus pulcher*) or relatively unapproachable (e.g., lingcod, *Ophiodon elongatus*) should be taped with substantially wider distance between fiducial marks.

From these examples of the precision and accuracy of this system, and factors affecting these measures, it is apparent that this system can be useful when properly configured and operated. It is particularly suited for use on fast-growing fishes with distinct breaks in length-frequency distributions between year classes, or on life stages where growth is fast. Similar systems could be used in research environments where fish handling conflicts with restrictions on the take or harassment of endangered fishes.

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LITERATURE CITED

Jahne, B. 1997. Practical handbook on image processing for scientific applications. CRC Press, Boca Raton, Florida, USA.

Zar, J.H. 1984. Biostatistical analysis. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, USA.

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AN ECONOMICAL, PORTABLE APPARATUS FOR CONDUCTING STATIC THERMAL AND CHEMICAL TOXICITY TESTS ON AMPHIBIAN EGGS AND LARVAE

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Researchers conducting static aquatic toxicity tests under field or laboratory conditions must ensure that test equipment minimizes stress to test organisms, does not contaminate test chambers, and avoids chemical or thermal degradation in test solutions (U.S. Environmental Protection Agency 1975, Anonymous 1987, American Society For Testing And Materials 1988). Test chambers used to conduct trials are generally maintained in constant-temperature waterbaths or other temperature-regulating devices, such as thermostat-controlled environmental chambers. In addition, flow-through systems are often used to ensure that stratification and chemical degradation do not develop in the test medium. The equipment used to achieve the aforementioned conditions may be quite sophisticated, but its expense (typically >US$1,000), bulkiness, relative fragility, and energy consumption makes it poorly suited to remote field or laboratory situations (e.g., DeFoe 1975, Lemke et al. 1978). Moreover, the fragile nature of young life stages of many aquatic test organisms and the physical properties of test solutions that prevent using aeration or standard mechanical stirrers to mix the test medium create numerous complications (Sanders 1970, Black et al. 1982). The following apparatus was designed to eliminate problems of thermal and chemical stratification in the test medium while providing a contaminant-free, low-stress environment for conducting static toxicity tests on developing amphibian embryos. Emphasis was placed on low cost, portability, ease of construction, and availability of materials.

The basic apparatus consists of a series of 5 test chambers (e.g., glass beakers or high-density polyethylene containers) placed over electric clocks with magnets attached to their second hands (Fig. 1 and 2). A magnetic stir bar placed in each container (or beaker) stirs the test solutions at the slow rate of 1 revolution/minute with the rotation of the second hand (Fig. 2).

Materials needed to build the apparatus can be purchased at local retailers (Table 1). Containers and magnetic stir bars can be purchased from scientific supply

[1] U.S. Environmental Protection Agency. 1975. Methods for acute toxicity tests with fish, macroinvertebrates, and amphibians. Ecology Research Series EPA-660/3-75-009. U.S. Environmental Protection Agency, Corvallis, Oregon, USA.

[2] Lemke, A.E., W.A. Brungs, and B.J. Halligan. 1978. Manual for construction and operation of toxicity-testing proportional diluters. Ecology Research Series EPA-600/3-78-072. U.S. Environmental Protection Agency, Duluth, Minnesota, USA.

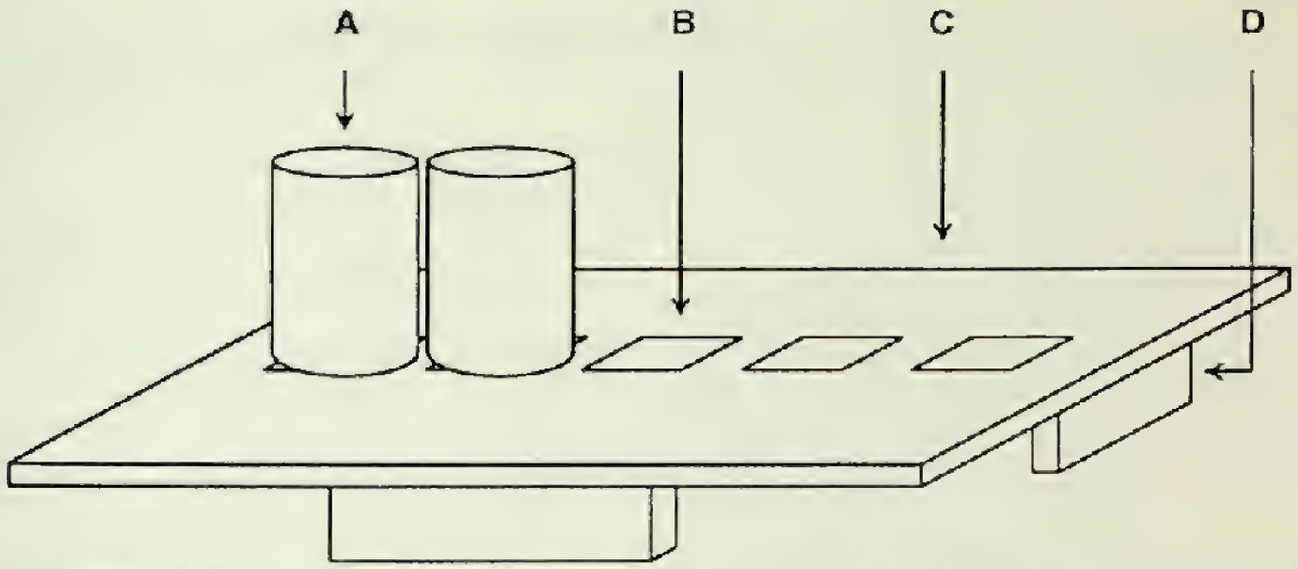

Figure 1. Front view of test apparatus showing partial locations of: A) test chamber, B) Plexiglas® inlay over clock with magnet on sweep second hand, C) baseboard, and D) baseboard support.

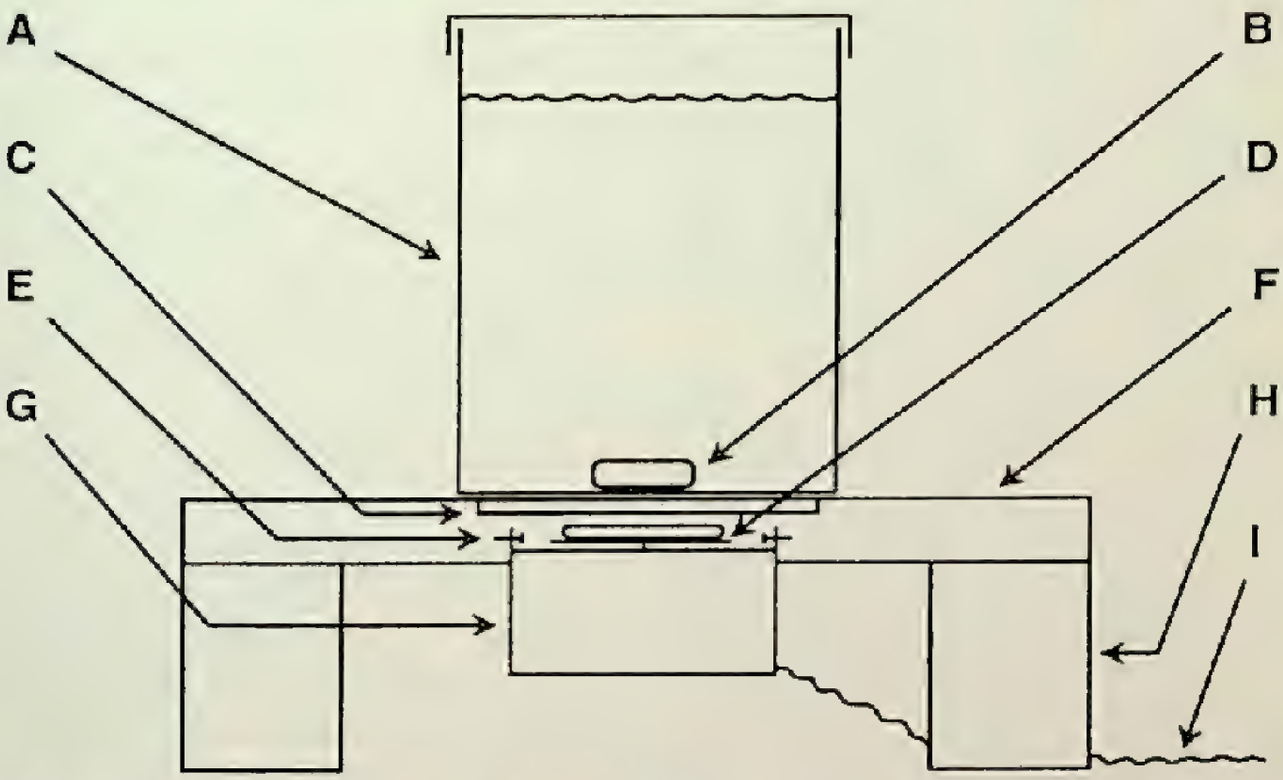

Figure 2. Side view of one test chamber of the apparatus. Letters refer to the following: A) test chamber with solution and cover, B) magnetic stir bar, C) Plexiglas® inlay, D) magnet on sweep second hand of clock, E) screw to attach clock to baseboard, F) baseboard, G) clock, H) baseboard support, and I) clock electric cord.

companies. Almost any inexpensive 110-120-VAC clocks are satisfactory, but they must have a sweep second hand and a removable bezel facing. Small hand-wound or battery-operated clocks may be better for remote field locations that lack an AC power source. This aspect of the apparatus can be easily customized, since many kinds of clock motors and sweep second hands are generally available from local clock dealers. Large (>2.5-cm long) rectangular magnets are available from local electronics stores. One entire apparatus can be constructed with tools no more

Table 1. Materials needed for constructing 2 test apparatuses each with 5 test chambers.

Amount	Item
1	244-cm (L) X 28.26-cm (W) X 1.91-cm (H) wood board
1	183-cm (L) X 8.89-cm (W) X 3.81-cm (H) wood board
10	120-VAC alarm clocks
1	0.080-gauge, 60.96-cm (L) X 76.20-cm (W) sheet of Plexiglas® or clear acrylic
2	88.7-ml tubes of silicone sealant
10	5.08-cm (L) X 0.79-cm (W) Teflon® stir bars with spinning ring
50	4d, 12-gauge, 3.81-cm (L) box nails
20	#8, 0.95-cm (L) wood screws
20	2.54-cm (L) X 1.91-cm (W) rectangular bar magnets
1	36.9-ml container of wood glue
10	5.68-liter high density polyethylene Bain Marie containers with covers or 4-liter Pyrex® beakers with 200-mm diameter watchglass covers

sophisticated than a hand drill and a coping saw. Presently, the total cost per test chamber is about US$12 (or US$60 per apparatus).

The apparatus is constructed by cutting 2 wooden baseboards into dimensions of 122-cm long, 28.26-cm wide, and 1.91-cm high. Baseboard supports (Fig. 1D) are nailed to the bottom sides and ends of each board. Five clocks (with bezels removed) are laid face down and equidistant on top of each baseboard and their outlines traced. The section of wood within each outline is removed with a drill and coping saw and inlays of Plexiglas® or clear acrylic are cut to dimensions slightly larger than each of the resulting holes (Fig. 2C). A chisel or router is then used to remove enough wood around each hole to allow for the placement of inlays flush with the surface of the baseboards (Fig. 2F). Finally, clocks with magnets glued to the second hands (Fig. 2D) are secured to the baseboard holes with screws placed through holes drilled into clock edges (Fig. 2E), and inlays are cemented into place with silicone.

Several aspects of the proposed apparatus encourage its use. Clocks, magnets, and other components of the apparatus can be easily repaired or replaced because of the simplicity of the apparatus. Gentle movement of the containers is all that is needed to adjust the position of magnetic stir bars during test trials and keep the them in the center of the bottom of each test container. A visual check of the clocks through the inlays is usually sufficient to determine if the magnets are rotating properly.

The most practical feature of this apparatus is its adaptability to remote field situations. Even when fully assembled, 1 apparatus takes up only a 122-cm x 29-cm x 30-cm space (approximately 0.34 m^2) and weighs only 1.5 kg, so it is easily portable. To facilitate transport, assembled baseboards of 2 apparatuses may be tied together and the test containers stacked and packed separately.

This apparatus also provides little chance of accidental injury to fragile organisms being tested. The slow rotation of the clock magnet results in the stir bar moving in short, irregular pulses that gently pushes eggs or non-mobile test organisms towards the outside edges of the containers, minimizing injury from the bars themselves. Moreover, I have not observed any ill effects on test organisms attributable to the

magnetic fields produced by the clocks or stir bars. Magnetic drives are common in submerged pump assemblies used by aquarists and aquaculturists (Straughan 1975, Axelrod 1986).

Many variations of this apparatus are possible. I have successfully used this apparatus to conduct salinity-tolerance tests on pre- and post-hatching stages of the California tiger salamander, *Ambystoma californiense*; California red-legged frog, *Rana aurora draytonii*; and foothill yellow-legged frog, *R. boylii*, but the system is easily adaptable to a wide variety of temperature-tolerance and static-toxicity tests on the developmental stages of amphibians, fishes, and other aquatic organisms. For example, I have also conducted temperature-tolerance tests on pre-hatching stages of the California red-legged frog by using circulating water baths inserted between the baseboard and test containers.

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LITERATURE CITED

American Society For Testing And Materials. 1988. Standard practice for conducting acute toxicity tests with fishes, macroinvertebrates, and amphibians. American Society For Testing And Materials Designation E 729-88. Annual Book of ASTM Standards, Philadelphia, Pennsylvania, USA.

Anonymous. 1987. Guidelines for use of live amphibians and reptiles in field research. American Society of Ichthyologists and Herpetologists (ASIH), The Herpetologists' League (HL), and Society for the Study of Amphibians and Reptiles (SSAR).

Axelrod, H.R. 1986. Starting your tropical aquarium. TFH Publications, Inc., Neptune City, New Jersey, USA.

Black, J.A., W.J. Birge, W.E. McDonnell, A.G. Westerman, B.A. Ramey, and D.M. Bruser. 1982. The aquatic toxicity of organic compounds to embryo-larval stages of fish and amphibians. U.S. Fish and Wildlife Service, Research Report 133:1-61.

DeFoe, D.L. 1975. Multichannel toxicant injection system for flow-through bioassays. Journal of the Fisheries Research Board of Canada 32:544-546.

Sanders, H.O. 1970. Pesticide toxicities to tadpoles of the western chorus frog *Pseudacris triseriata* and Fowler's toad *Bufo woodhousii fowleri*. Copeia 1970:246-251.

Straughan, R.P.L. 1975. Keeping live corals and invertebrates. A.S. Barnes and Co., Inc., Canbury, New Jersey, USA.

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USE OF MILITARY HELICOPTERS TO SURVEY AN ELK POPULATION IN NORTH COASTAL CALIFORNIA

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Monitoring wildlife populations is a daunting task because of the large financial costs and time requirements to conduct surveys (e.g., Thompson and Bleich 1993, McCullough et al. 1994, Garshelis and Visser 1997). Consequently, investigators are constantly seeking new methods or protocols that are reliable and more efficient. We had an opportunity to determine if repeated surveys using military helicopters could be developed into a reliable protocol to monitor a Roosevelt elk population in north coastal California. Military commanders have been receptive to donating helicopter time and crews to government agencies to assist with aerial data collection. In some situations, quality of data and safety have been compromised when flying time, pilots, and some observers have been provided gratis (Bleich 1983). Nevertheless, we investigated the possible use of military aircraft and crew because aerial surveys are commonly conducted for elk populations, safety is a priority with the military, data on elk population trends in north coastal California are scant, and funding to conduct surveys is precarious (Weckerly 1996). Our objective was to compare counts from helicopters with intensive ground searches for a Roosevelt elk population that inhabited a densely vegetated landscape (Weckerly and Ricca[1] 1995).

The study was conducted in a 40-km^2 forest of coastal redwoods, *Sequoia sempervirens*, and Douglas fir, *Pseudotsuga menziesii*, near Smith River, Del Norte County, California that was described in detail by Weckerly and Ricca[1] (1995). Approximately 35% of the forest consists of 0- to 5-year-old stands. Meadows make up <1% of the study area and are found along the lower reaches of drainages. There are numerous small streams and the terrain is rugged. Elevation ranges from 0 to 300 m.

Eight surveys using HH-65A helicopters were conducted from 13 January to 18 April 1997. At that time, leaf drop on deciduous trees and shrubs afforded greater visibility and these flights coincided with ground-based searches (distribution surveys). Helicopter surveys were flown during mid-morning, required 1-1.5 h to

[1] Weckerly, F.W. and M.A. Ricca. 1995. Developing a reliable population monitoring program of Roosevelt elk occupying dense coniferous forests. Unpublished report, California Department of Fish and Game, Sacramento, California, USA.

complete, and covered the same area as ground distribution surveys. Only 1 survey was performed per week. Under calm conditions, pilots flew at speeds of about 40 km/h and about 25 m above ground level; surveys were flown at faster speeds and at higher elevations under windy conditions. The area surveyed had been shown in the previous 2 years to possess 95% of all elk sign found in the entire 98-km^2 study area (Weckerly[2] 1996, Weckerly[3] 1997). Helicopter surveys alternated starting points from the north to the south end of the study area. When elk were spotted, the pilot circled and allowed the crew to count as many individuals as possible. Also, the habitat (open or forested) where the group was initially found was recorded. A military crew member, the copilot, and K.E. Kovacs participated in counts. No communication took place among the authors and military personnel about the helicopter and distribution surveys until after 18 April. K.E. Kovacs had 9 years of experience conducting aerial surveys of large mammals.

Ten weekly distribution surveys were conducted from 18 January to 29 March 1997 by F.W. Weckerly, a field technician, and 1-3 volunteers using the technique described by Weckerly and Ricca[1] 1995. Using data from these distribution surveys, we estimated minimum population size. Groups of Roosevelt elk composed mostly of cows and calves display strong social bonds and a high degree of group stability (Jenkins and Starkey 1982, Weckerly[2] 1996). Assuming groups of cows and calves are stable, we totaled the largest counts of groups from 3 parts of the survey area: South Fork Winchuck, Gilbert, and Ritmer watersheds; Rowdy and Dominie watersheds; and south of the town of Smith River along State Highway 101. Over the past 3 years, at least 3 groups of cows and calves were found in these distinct geographic regions during 17 of 30 distribution surveys (Weckerly and Ricca[1] 1995, Weckerly[2] 1996, Weckerly[3] 1997). We used a G test to assess if the proportion of elk groups detected in forested and open (meadows and 0- to 5-year-old stands) habitats differed between the 2 methods (Sokal and Rohlf 1995).

A mean of 27 (SD = 19) elk was sighted during 8 helicopter surveys. Counts, sorted from low to high, for each survey were: 3, 9, 16, 20, 31, 35, 38, 64. The proportion of groups (n = 19) located in open habitats (meadows and 0- to 5-year-old stands) was 0.895.

A mean of 69 (SD = 16) elk was counted in the 10 distribution surveys. The counts for each survey, arranged from low to high, were: 32, 37, 63, 63, 63, 79, 79, 79, 90, 109. The proportion of groups (n = 47) sighted in open habitats was 0.787.

Helicopter surveys observed proportionally more groups of elk in open habitats than the distribution surveys ($G = 31.8$, $df = 1$, $P < 0.0001$). Summing the maximum number of elk counted in the 3 distinct regions yielded a minimum population size

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[2] Weckerly, F.W. 1996. Monitoring populations of Roosevelt elk in dense coniferous forest: Patterns of distribution, development of distribution surveys and population simulation. Unpublished report, California Department of Fish and Game, Sacramento, California, USA.

[3] Weckerly, F.W. 1997. Monitoring Roosevelt elk in north coastal California: Suitable habitat, sex ratio and sexual segregation, and population estimation. Unpublished report, California Department of Fish and Game, Sacramento, California, USA.

of 120 (Winchuck-Gilbert-Ritmer = 58, Dominie-Rowdy = 32, South Smith River = 30).

Our findings do not bode well for using military helicopters to collect data to measure trends in elk populations inhabiting densely vegetated landscapes. The number of elk observed by helicopter, on average, was less than one-half the number counted from distribution surveys and the helicopter survey with the highest count was only 53% of the estimated minimum population size.

Groups of elk fleeing before complete enumeration and poor visibility of elk in dense vegetation are probably reasons why aerial counts were so low. When the aircraft circled to enumerate a group, individuals fled and some probably reached cover before they could be counted. Moreover, once elk entered dense vegetation they did not leave. The difficulty of detecting elk in temperate rain forests has been noted previously (Houston et al. 1987) and Bleich et al. (1990, 1994) discussed the effects of similar responses by mountain sheep on aerial survey results. Detection of elk in forests may have been higher during distribution surveys because elk sign was first detected and then search effort was focused on an area with recent sign. No such clues about elk distribution were available when flying in a helicopter.

Observer experience has been associated with detection of large herbivores from aircraft and may partially explain why aerial counts were so low (LeResche and Rausch 1974). On each flight, 2 observers with little or no experience participated in surveys, but the distribution surveys also used inexperienced personnel: 18 aerial survey participants and 13 distribution survey participants had no previous experience. Either undercounting is a greater problem when using inexperienced personnel during aerial surveys or distribution surveys offer more promise to detect elk inhabiting densely vegetated coniferous landscapes.

Our findings support the contention of Bleich (1983) that aerial surveys using untrained personnel and gratis equipment offer little promise to reliably monitor populations of large mammals. Although the aerial surveys reported herein were cost and time efficient, the low numbers observed and associated high variance indicate that little meaningful data can be gleaned on population trends using this technique.

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LITERATURE CITED

Bleich, V.C. 1983. Comments on helicopter use by wildlife agencies. Wildlife Society Bulletin 11:304-306.

Bleich, V.C., R.T. Bowyer, A.M. Pauli, M.C. Nicholson, and R.W. Anthes. 1994. Mountain sheep (*Ovis canadensis*) and helicopter surveys: Ramifications for the conservation of large mammals. Biological Conservation 45:1-7.

Bleich, V.C., R.T. Bowyer, A.M. Pauli, R.L. Vernoy, and R.W. Anthes. 1990. Responses of mountain sheep to helicopter surveys. California Fish and Game 76:197-204.

Garshelis, D.L. and L.G. Visser. 1997. Estimating megapopulations of wild bears with an ingested biomarker. Journal of Wildlife Management 61:466-480.

Houston, D.B., B.B. Moorhead, and R.W. Olson. 1987. Roosevelt elk density in old growth forests of Olympic National Park. Northwestern Science 61:220-225.

Jenkins, K.J. and E.E. Starkey. 1982. Social organization of Roosevelt elk in an old growth forest. Journal of Mammalogy 63:331-334.

LeResche, R.E. and R.A. Rausch. 1974. Accuracy and precision of aerial moose censusing. Journal of Wildlife Management 38:175-182.

McCullough, D.R., F.W. Weckerly, P.I. Garcia, and R.R. Evett. 1994. Sources of inaccuracy in black-tailed deer herd composition counts. Journal of Wildlife Management 58:319-329.

Thompson, J.R. and V.C. Bleich. 1993. A comparison of mule deer survey techniques in the Sonoran desert of California. California Fish and Game 79:70-75.

Sokal, R.R. and F.J. Rohlf. 1995. Biometry: The principles and practice of statistics in biological research, 3rd edition. W.H. Freeman and Company, San Francisco, California, USA.

Weckerly, F.W. 1996. Roosevelt elk along the Prairie Creek drainage: An evaluation of estimating abundance and herd composition. California Fish and Game 82:175-181.

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CONSUMPTION OF JUVENILE SALMONIDS BY ADULT STEELHEAD IN THE COWLITZ RIVER, WASHINGTON

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On the Pacific coast of North America, adult hatchery steelhead, *Oncorhynchus mykiss*, commonly return to streams where wild salmonid juveniles also are present. These adult fish may prey on wild juveniles, possibly impairing already depressed populations. Groot and Margolis (1991) mention many instances where salmonids prey on juvenile Pacific salmon. Although some adult Pacific salmon, such as chum, *O. keta*, and pink salmon, *O. gorbuscha*, are thought not to feed in freshwater (Scott and Crossman 1973), others, such as sea-run cutthroat trout, *O. clarki*, do actively feed (Trotter 1997). In the only literature we found on adult steelhead feeding in freshwater, Burns (1974) reported that 95% of steelhead contained food items in Deer and Mill creeks, tributaries of the Sacramento River in California. The most prevalent food items were Trichoptera, followed by aquatic plants and eggs of chinook salmon, *O. tschawytscha*; no juvenile fish were reported. If such a high incidence of feeding involved juvenile salmonids, curtailment of hatchery steelhead programs in some streams might be warranted to protect juveniles of other species. Our study was conducted to add information to that known about the frequency of adult steelhead predation on juvenile salmonids.

The Cowlitz River, a tributary of the lower Columbia River at river kilometer (rkm) 108 (Fig. 1), was chosen as the study site because adult hatchery steelhead and juvenile salmonids were both abundant. From May through October 1994 and 1995, Cowlitz River recreational anglers harvested 12,540 and 7,664 adult summer steelhead, respectively (Washington Department of Fish and Wildlife [WDFW] punchcard data, Olympia, Washington). Summer, rather than winter, steelhead were chosen for this study because winter steelhead were thought to be less likely to prey on juvenile salmonids due to shorter freshwater residency prior to spawning, slower metabolism associated with cooler water temperatures in winter, and reduced abundance of juvenile salmonids in winter. Adult summer steelhead enter the Cowlitz River from May through August and spawn in December and January, whereas winter steelhead enter the river from November through April and typically spawn within a month of arrival. About 80% of Cowlitz River adult summer steelhead enter freshwater after 2 years of ocean residence and are about 62-70 cm fork length (Tipping[1] 1997). Angling regulations allow only the harvest of hatchery-origin fish, identified by the absence of the adipose fin, previously excised from juvenile fish before release.

From March through June 1994 and 1995, two hatcheries on the river released a

[1] Tipping, J.M. 1997. Cowlitz fish biologist annual report for 1996. Washington Department of Fish and Wildlife #H97-03, Olympia, Washington, USA.

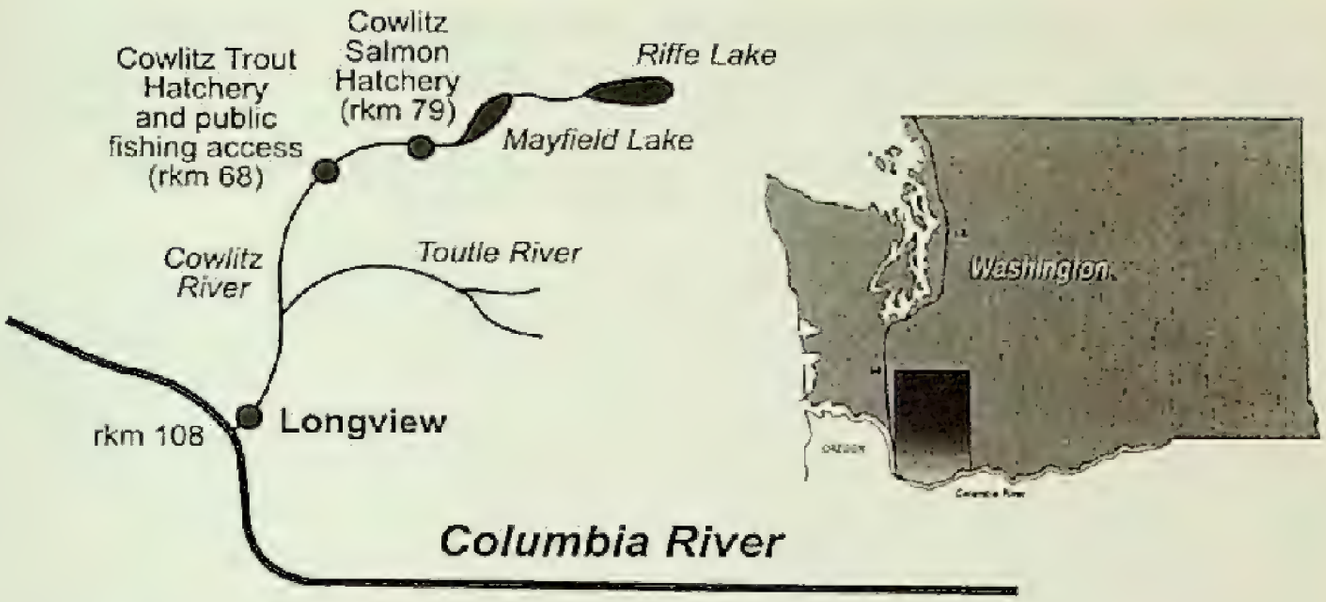

Figure 1. Map of the Cowlitz River with locations of hatcheries noted.

total of 25.4 million juvenile coho salmon, *O. kisutch*; chinook salmon; sea-run cutthroat trout; and steelhead (WDFW planting records, Olympia, Washington). Each year several hundred to thousands of adult fall chinook salmon, spring chinook salmon, coho salmon, and steelhead also spawn naturally in the river (WDFW spawning escapement records, Vancouver, Washington) and produce offspring that may be susceptible to predation by adult steelhead returning from May through October. Although many juvenile salmonids undoubtedly emigrate from the Cowlitz River to the ocean before June, about 6 million juvenile hatchery chinook salmon are liberated in June and some fish from prior liberations may be still present in the river. In addition, based on their extended freshwater life history, many naturally produced juvenile salmonids are present after June. The hatcheries are located and release fish at rkm 68 and rkm 79 (Fig. 1). Most natural spawning (WDFW spawning escapement records, Vancouver, Washington) and much of the recreational fishery occurs between the 2 hatcheries.

We collected stomachs from adult hatchery summer steelhead caught by anglers on the Cowlitz River from June through October 1994 and 1995. Most steelhead stomachs were obtained from anglers using a public access at rkm 68. Boat anglers, commonly fishing from 11 km above to 20 km below the access, caught most of the sampled fish. Collection dates of individual stomachs were not recorded, but most were gathered in July and August, a reflection of angler effort and fish abundance. Steelhead stomachs were injected with a small amount of 37% formalin and placed in 100% ethanol until dissection. During dissection, longitudinal cuts were made through the sides of the stomach. Contents were removed, placed in jars of ethanol, and identified with the unaided eye. Particular care was taken in looking for the remains of fish.

Of 1,041 stomachs examined (n = 232 in 1994, n = 809 in 1995), 116 (11%) contained food, including salmon roe and ghost shrimp, *Callianassa californiensis* (anglers' baits) (84 stomachs); insects (4 stomachs); and detritus (26 stomachs).

Two stomachs (0.2%) sampled in 1995 contained the remains of 4 salmonids in moderate stages of digestion. One fish was identified as a juvenile coho or chinook salmon based on bone structure and the other 3 could not be identified beyond genus (C. Frost, National Biological Service, personal communication.). Fork lengths of the 4 salmonids consumed were estimated to be 6-9 cm.

The observed low incidence of juvenile salmonids in the stomachs of adult summer steelhead suggests that the hatchery summer steelhead program on the Cowlitz River does not impair sympatric populations of juvenile salmonids through predation. However, quantification of juveniles consumed is difficult without knowing the daily evacuation rates of adult steelhead and the daily number of adult steelhead present. Burns (1974) examined steelhead from October through January in 2 Sacramento River tributaries about 160 km from salt water and suggested that feeding was necessary for fish to maintain themselves until spring spawning. In contrast, our observations suggest that adult summer steelhead sampled from June through October in the Cowlitz River (176 km from salt water) had sufficient energy reserves to carry them through December spawning and that they infrequently fed in fresh water. Although both studies indicate minimal predation on juvenile salmonids, the difference in feeding rates in the 2 studies is as different as their distance geographically; a similar study conducted midway would be of interest.

ACKNOWLEDGMENTS

We thank C. Frost for identifying fish remains and T. Tynan, A. Appleby, H. Fuss, and R. Fuller for reviewing the manuscript. Tacoma Public Utilities funded a portion of this work.

LITERATURE CITED

Burns, D.C. 1974. Feeding by mature steelhead in the spawning stream. California Fish and Game 60:205-206.

Trotter, P.C. 1997. Sea-run cutthroat trout: Life history profile. Pages 7-15 *in:* J.D. Hall, P.A. Bisson, and R.E. Gresswell, editors. Sea-run cutthroat trout: Biology, management, and future conservation. Oregon Chapter, American Fisheries Society, Corvallis, Oregon, USA.

Groot, C. and L. Margolis, editors. 1991. Pacific salmon life histories. The University of British Columbia Press, Vancouver, British Columbia, Canada.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada, Bulletin 184.

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CALIFORNIA FISH AND GAME EDITORIAL POLICY AND INSTRUCTIONS TO AUTHORS

California Fish and Game is a regional, scientific journal devoted primarily to the conservation and understanding of California's flora and fauna, but it also accepts papers from the west coast of North America and the northeast Pacific Ocean. Original manuscripts providing information of direct interest and benefit to California researchers and managers are welcome. The journal accepts the following types of contributions: 1) *Articles* include reports of studies of broad scope, critical reviews, and in-depth essays (perspective articles) on subjects of concern to the professional and layperson. 2) *Notes* are short papers of limited scope that present new knowledge worthy of publication. 3) *Comments* are opinions on topics already published in the journal; responses from the original authors will be invited.

If the journal's contents are reproduced elsewhere, the authors and *California Fish and Game* should be acknowledged.

THE MANUSCRIPT

Submit 4 copies (retain the original) of manuscripts directly to the Editors-in-Chief at the address on the inside, front cover of the journal, accompanied by a cover letter that 1) states the category (article, note, or comment) intended for the paper; 2) describes other manuscripts or published material that contain the same or similar information; 3) lists colleagues who have seen the draft manuscript; 4) lists potential referees; 5) specifically accepts page charges (US$40.00 per page); and 6) contains the phone and FAX numbers, and e-mail addresses of the corresponding author.

Manuscripts should be printed letter-quality on standard white bond paper. Draft figures and illustrations are acceptable for the initial review process. Double-space all material, including the abstract, text, figure captions, tables, and literature cited. Provide ample margins, at least 2.5 cm on all sides. Do not hypenate at the right margin or right-justify text.

Number pages, including tables and literature cited. Type each table on a separate sheet. Each section must immediately follow the previous section; do not start on a new page. Include an initial statement in the introduction explaining the purpose or objective(s) of the work.

Articles must be introduced by a concise, single-paragraph abstract. Notes do not include an abstract.

Very long articles should also have a concise summary, understandable without reference to the text.

Avoid the passive voice, lengthy tables or appendices, repetition, and long lists of little interest except to the author. Personal pronouns may be used when they do

not create strained phrasing.

Punctuate and proofread carefully. Check all equations for accuracy. Assure consistency between "Literature Cited" and citations in the text. Inattention to detail aggravates editors and affects referees' opinions of the manuscript.

The journal follows the CBE Style Manual (Sixth Edition) in most matters, but use these instructions and a recent issue of *California Fish and Game* as definitive guides in the correct preparation of manuscripts.

UNITS OF MEASUREMENT

The metric system is used exclusively in *California Fish and Game* because of its worldwide acceptance. The modernized metric system, "Systeme International d'Unites" (SI), is the preferred system. This system provides unambiguous symbols, standard in all languages, for units of measurement. The CBE Style Manual contains a discussion of the SI, as well as conversion factors from common English measurements to metric.

TABLES AND FIGURES

Tables and figures are numbered consecutively beginning with "1". Refer to tables and figures by number in the manuscript. Do not say "as shown in the following table," because the table in question may not immediately follow that statement in final placement.

Make complete statements of fact in the text. Use figures and tables only as supporting references. For instance, avoid statements like "Table 1 shows the estimated rate of exploitation and expectation of deaths from natural causes." Rather, state: "Estimated exploitation rate and expectation of death from natural causes were 50% higher in 1962 than in any of the next 6 years (Table 1)." In this way the reader is never forced to search out Table 1 to understand the text.

In the text, abbreviate Figure as "Fig." Use initial capitals for "Fig." and "Table."

Tables

Think carefully about table layout; most tables can be formatted to fit the standard page width of the journal (119 mm). Deviate from this (portrait) format to landscape format only as a last resort.

Table headings should contain sufficient information for tables to stand alone without reference to the text. Capitalization in table headings should follow the

Table 1. Age at which the first spawning check was observed in scales from Sacramento suckers from Thomes Creek, California, 1981.

	Age (percent composition)			
Sex	4	5	6	7
Female	7.7	49.2	37.2	5.9
Male	8.3	58.3	31.1	2.2

same format as other text, as illustrated in example Table 1.

In column headings and row labels, capitalize first letter of initial word only, as in "Age at maturity." Underline column headings, but do not include any other horizontal or vertical rules in tables. Horizontal rules, as shown in example Table 1, will be inserted by the editors.

Use tabs (1 tab between column headings and column entries), not the space bar, to space between columns. No other spacing should be included between columns.

Figures

Figure captions should contain sufficient information for figures to stand alone without reference to the text. Type all figure captions consecutively, double-spaced, on a separate page following the Literature Cited section at the end of the manuscript. Do not attach captions to figures.

Identify figures on the back with last name of author(s) in the upper left-hand corner and the figure number in the upper right-hand corner.

Submit figures that can be satisfactorily reduced to the format of the journal. Reductions should not exceed 50%. Take care that lines and lettering are large enough to be legible when reduced to the size of the journal page. Lettering style should be the same throughout.

Consider proportions of figures in relation to the page size of *California Fish and Game*. The usable printed page size is 119 by 187 mm. This must be considered in planning a figure, since the figure with its caption cannot exceed these limits. To the extent possible, figures should be sized and oriented so that they occupy only part of a page of the journal.

Maps are only necessary when they show detail, such as sampling sites, not available in a standard atlas. Maps should show the scale in kilometers and compass direction. Latitude and longitude on the appropriate borders are often desirable. An inset location map is generally useful.

Illustrations drawn to scale should be so indicated in the figure caption.

Photographs

Submit prints (black and white only) on glossy paper. Remember that the printed halftone will not be as clear as the photograph. A fuzzy photo cannot yield anything but a muddy printed product.

As for figures, consider the shape of the print. Crop items that distract from the central object such as out-of-focus foreground and overbalancing areas of sky.

Pack photographs carefully before mailing and provide backing. Cracks on prints will show in the halftone. Do not put paper clips on photographs. Never write on the back of photographs or figures with any object harder than a soft tip pen or china marking pencil.

Captions for photographs should include the name of the photographer and, if appropriate, the month and year in which the photo was taken. Use "Photograph by

author" if that is the case.

TITLES AND SUBTITLES

Follow this pattern in setting up titles and subtitles:

TITLE IN CAPS

AUTHOR IN CAPS
Organization in Initial Caps
Complete Mailing Address in Initial Caps

MAJOR SUBHEAD - CENTER CAPS

Next Subhead - Center, Initial Caps Only

Third Subhead - Left Margin, Italicized, Initial Caps Only

Fourth subhead italicized - Indented as a paragraph with the text following like this sentence.

FOOTNOTES

A footnote with the author's name is used to reflect the present address of the author if different from the address while doing the work (e.g., [1] Current address:).

Use of footnotes should be minimized. Their most common use is for citation of nonprimary (gray) literature not appropriate for inclusion in "Literature Cited." If used, they should be denoted by superscript numbers, numbered consecutively (1, 2, ...) throughout the manuscript, and placed on a separate page after "Literature Cited" and before any figure captions.

Footnotes in tables should be consecutive lowercase letters (a, b, ...) and the sequence begins again in each table. Table footnotes should be placed below the body of the table.

MEASUREMENTS

Use Arabic numerals in preference to words when numbers are counts or measurements, as "7 quail" or "3 mm." Treat ordinal numbers in the same manner (3rd, 33rd). Never begin a sentence with an Arabic numeral (spell out the number) or use numerals for 2 consecutive numbers (e.g., "two 3-liter flasks," not "2 3-liter flasks").

Show temperatures in degrees Celsius with the abbreviation °C.

Give latitude and longitude in the form: 33°41'30"N, 118°09'05"W.

Dates are expressed as: 23 January 1998.

Use the 24-hour system for time of day: 1100 hours.

ABBREVIATIONS

Abbreviations should be used sparingly. The following abbreviations are used in *California Fish and Game* without definition:

alternating current	AC
centimeter(s)	cm
confidence interval	CI
degree (angular measure or degree Celsius)	°
degree Celsius	°C
degrees of freedom	df
direct current	DC
east	E
gram(s)	g
hectare	ha
kilogram(s)	kg
kilometer(s)	km
lethal concentration, 50%	LC50
lethal dose, median	LD50
logarithm (base 10)	log, $\log_{10}$
logarithm (base e)	ln, $\log_e$
meter(s)	m
microgram	µg
micron(s) (10^{-3} mm)	µm
milligram(s)	mg
milliliter(s)	ml
millimeter(s)	mm
minute(s) (angular measure)	′
north	N
parts per billion	ppb
parts per million	ppm
parts per thousand	‰
percent	%
probability	*P*
second(s) (angular measure)	″
south	S
species (taxonomy only, singular)	sp.
species (plural)	spp.
standard deviation	SD
standard error	SE
volt	V
west	W

Express measurements of area and volume with exponents, not with letter abbreviations (e.g., "m^2," not "sqm" and cm^3," not "cc").

Express ratios and densities with a slash (/) (e.g., number/m^2) if there is only 1 unit in the denominator. Multiple slashes in an expression are ambiguous, so write a unit such as "catch per angler per day" as "catch/(angler-day)," not "catch/angler/day."

CAPITALIZATION

Do not capitalize common names of organisms.

Capitalize bay, city, county, river, street, and similar words only when they form part of a name: Humboldt Bay, Shasta County, City of Stockton; but Humboldt and Shasta counties or American and Sacramento rivers.

Do not capitalize northern and southern in the expressions northern California and southern California. Capitalize the word State when it stands alone and refers to California. Capitalize Department in referring to the Department of Fish and Game.

STATISTICAL RESULTS

Results of statistical tests should be presented in full in the text. This includes the value of the test statistic (e.g., $F =$, $t =$, $\chi^2 =$), degrees of freedom (df =), and probability of wrongly rejecting the null hypothesis ($P =$). Place the test results in parentheses following the statement of the statistical conclusion, using correct internal punctuation (e.g., $F = 5.61$; df = 1, 9; $P = 0.02$). Probability can be expressed as an exact value or as greater than (>) or less than (<) a critical value, but the same convention should be used throughout the manuscript. If multiple statistical tests were conducted and all yielded the same (significant or nonsignificant) results, each test statistic need not be presented. Instead, provide the name of the test and the relation of the resultant probabilities to the critical value (e.g., ANOVA, all $P < 0.05$).

In tables, if probabilities are not presented in a separate column, indicate significance of tabular values with asterisks (*, **, ***) and define the values for these symbols in the figure caption (e.g., * $P < 0.05$, ** $P < 0.01$).

PREPARATION OF COPY

Wide availability of word processing software allows production of copy with boldface, italics, small caps, etc. Use typesetting conventions (e.g., 1 underline for italics) only if appropriate word processing software is not available.

Scientific names are always italicized. Italicize only the generic name when unknown or multiple species are denoted, as *Sebastes* sp. or *Sebastes* spp. Scientific names should be set off with commas, as "mosquito fish, *Gambusia affinis*, in Golden Pond."

Spell out fish length designations, followed by abbreviations in parentheses (FL, SL, or TL), the first time you use them. Thereafter, use abbreviations only. Better yet, describe the measurement technique in the Methods section and eliminate the subsequent need for length designations.

Capitalize and italicize names of vessels: *LONGFIN*, *DAVID STARR JORDAN*.

In the text, italicize names of books, journals, and similar literary works. Do not italicize citations in the Literature Cited section.

Be especially careful with hyphens. Most authors tend to hyphenate many words which should be written unhyphenated. Note particularly that commonly used prefixes and suffixes (such as inter, like, mid, non, over, post, pre, semi, sub, under) usually are not hyphenated. Compound modifiers normally are hyphenated (e.g., 25-mm specimen, deep-water fishes), unless the first word of the compound modifier is an adverb.

Use parentheses and Arabic numerals to label enumerations included in a sentence or paragraph, as "The primary objectives of this study were to determine 1) food habits, 2) effects of hunting, and 3) extent of depredations on agricultural crops of wintering mallards."

COMMON AND SCIENTIFIC NAMES

The scientific name of a species should be introduced the first time the common name is used in the abstract and in the text. Thereafter, use the common name in text, tables, and figures unless no recognized common name exists. If a great many species are under consideration, it is permissible to use common names in the text and to list common and scientific names in an appendix or table. Do not include a scientific name in the title unless no common name exists or the manuscript deals primarily with systematics or a range extension of a species that is rare in California.

ACKNOWLEDGMENTS

Acknowledgments generally should be in the order of assistance rendered or alphabetized within an organization if more than 1 individual gave the same help. Grants-in-aid and other funding sources should be included in this section. Use only initials of given names, but spell out the entire names of organizations, unless an abbreviation has been defined earlier in the text.

LITERATURE CITED

List citations, double-spaced, in alphabetical order at the end of the manuscript. Your list must be headed "LITERATURE CITED." All entries must be cited in the text.

Avoid extensive references to nonprimary (gray) literature, such as unpublished agency reports, M.S. theses, Ph.D dissertations, and technical reports with limited distribution. Reports with limited or no peer review fall into the gray literature category. Gray literature cited in the text should not be included in "Literature Cited"; instead, it should appear on a separate page following "Literature Cited" and should follow the same format as primary literature citations (see "Footnote" section).

Check all citations carefully against the original publications, especially titles and dates. Refer to them in the text using the name-and-year system. Where there

are 3 or more authors, use "et al." for the junior authors in the text, as "Turner et al. (1969)," but list all authors in "Literature Cited."

Multiple references cited in the text should be in chronological order, as "(Lea 1975, Herrgesell 1984, Hashagen 1985)." A gray literature citation should have the superscript footnote number following the author's name, as "Zielinski[1] (1992)." Citations for direct quotations in the text should include the page number from which the quotation was drawn, as "(Moyle 1976:144)."

Write out the names of periodicals completely (e.g., Transactions of the American Fisheries Society, California Fish and Game, Wildlife Monographs). Include the periodical issue number only if page numbers are not consecutive from issue to issue. Omit the number of pages in books, bulletins, and symposia proceedings if the entire publication is cited. Spell out the names of cities and states (or other appropriate governmental or geographic unit) where publishers are headquartered and include the country (e.g., USA, Ireland).

Examples of the general style used in *California Fish and Game* are shown below.

Periodical or journal:

Duffy, J.M. and H.J. Bernard. 1985. Milkfish, *Chanos chanos* (Forsskol, 1775), taken in southern California adds new family (Chanidae) to the California marine fauna. California Fish and Game 71:122-125.

Article as part of a bulletin or book:

Quast, J.C. 1968. Fish fauna of the rocky inshore zone. Pages 35-55 *in*: W.J. North and C.L. Hubbs, editors. Utilization of kelp bed resources in southern California. California Department of Fish and Game, Fish Bulletin 139.

Book:

Watt, K.E.F. 1968. Ecology and resource management: A quantitative approach. McGraw-Hill Co., New York, New York, USA.

Two or more papers by same author in same year:

In text: (McCoid and Fritts 1980a, b).

In "Literature Cited":

McCoid, M.J. and T.H. Fritts. 1980a. Observations of feral populations of *Xenopus laevis* (Pipidae) in southern California. Bulletin of the Southern California Academy of Science 79:82-86.

McCoid, M.J. and T.H. Fritts. 1980b. Notes on the diet of a feral population of *Xenopus laevis* (Pipidae) in California. Southwestern Naturalist 25:272-275.

These general rules apply:

1) Only proper nouns are capitalized.

2) Initials are substituted for given names.

3) The words "volume" and "number", or their equivalents in foreign languages, are not used in citing periodicals.

4) Unpublished papers are not cited in "Literature Cited". If they must be used,

they may be footnoted. Papers "in press" can be cited if they are being published in the peer-reviewed primary literature; if in the gray literature, they should be footnoted.

5) Personal communications are not cited in "Literature Cited"; they are cited in the text as "(A.J. Cordone, California Department of Fish and Game, personal communication)." Subsequent personal communications would be cited as "(A.J. Cordone, personal communication)."

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Upon receipt by the Editors-in-Chief, a manuscript will be acknowledged and forwarded to the appropriate associate editor, who will then have the manuscript reviewed by at least 2 referees. When reviews are complete, the associate editor will send the reviewed manuscript, with a recommendation for acceptance or rejection, back to the Editors-in-Chief. The Editors-in-Chief will forward referees' comments and an acceptance or rejection notice to the author with further instructions. Manuscripts are generally published in the order accepted by the Editors-in-Chief, within space limitations of the journal.

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An electronic copy of the final, accepted manuscript is required before publication. This diskette copy should be in PC (not MacIntosh) word-processor or text format. Tables, figure captions, and footnotes can be included in the same document as the text, or in separate documents. If they are included in the same document, tables should each be on a separate page; figure captions can all be included on 1 page, as can footnotes. As noted earlier, it is imperative that spaces between columns in tables be created with tabs, not the spacebar, with only 1 tab between columns. Do not include horizontal or vertical lines in tables; however, column headings should be underlined. Also, do not use the "table" function in your word processor; it will not translate into our desktop publishing software. If the diskette copy of your manuscript does not follow these conventions, it will be returned for correction.

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Major revisions are not normally necessary in proof. Do not add or rewrite portions of your paper at this stage unless serious misstatements or misinterpretations will result. However, sometimes the Editors will allow a manuscript to proceed to

the galley-proof stage while some questions or revisions remain in order to facilitate timely publication.

INSTRUCTIONS FOR AUTHORS

MANUSCRIPTS: Refer to the CBE Style Manual (5th Edition) and a recent issue of *California Fish and Game* for general guidance in preparing manuscripts. Specific guidelines are available in *California Fish and Game* 84(1):51-60.

COPY: Use good quality 215 x 280-mm paper. Double-space throughout with 25-mm margins. Do not hyphenate at the right margin or right-justify text. Authors should submit four good copies of their manuscript, including tables and figures, to the Co-Editors-in-Chief. An electronic copy of the manuscript on diskette in word processor format will be required with the final accepted version.

CITATIONS: All citations should follow the name-and-year system. See a recent issue of *California Fish and Game* for the format of citations and Literature Cited. Completely spell out publication and periodical names in Literature Cited. Minimize references to unpublished ("gray") literature. Gray literature citations should be in footnotes.

ABSTRACTS: Articles, but not notes, must be introduced by an abstract. Abstracts should be about 1 typed line per typed page of text. In 1 paragraph describe the problem studied, most important findings, and implications of the results.

TABLES: Start each table on a separate page and double-space throughout. Do not use vertical rules. Use tabs, not the spacebar, to space between columns. Footnotes in tables should be consecutive lower-case letters, with the sequence beginning again in each table.

FIGURES: Consider proportions of figures in relation to the usable page size of *California Fish and Game* (119 x 187 mm). Figures, including captions, cannot exceed this size when reduced to the format of the journal. Figures and line-drawings should be clear, with well-defined lines and lettering. Lettering style should be the same throughout and large enough to be readable when reduced to finished size. Type figure captions on a separate page. High-quality photographs with strong contrast are acceptable and should be submitted on glossy paper. On the back of each figure or photograph, lightly write the figure number and senior author's last name. Be prepared to provide high-quality, scannable, original figures or graphics files on diskette with the final accepted manuscript.

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